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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

INCLUDING THE

PROGRAMME OF THE

1959 SPRING MEETING

AT

WASHINGTON, D. C.

April 30, May 1 and 2, 1959

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April 30, 1959 Series II, Vol. 4, No. 4

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

1959 Washington Meeting, April 30, May 1 and 2, 1959

THE **1959 Spring Meeting** of The American Physical Society will be held in **Washington, D. C.,** on **Thursday, April 30, Friday, and Saturday, May 1 and 2.** The sessions will be distributed in a way that will seem quite novel to the very junior members of the Society, but to their seniors will be reminiscent of times gone by. Some of the sessions will be in halls of the Willard Hotel, which is at the corner of 14th Street and Pennsylvania Avenue (all addresses here given are to be supplemented with N.W. when needful). Some will be in the Departmental Auditorium, a Government building which has one large hall known by the same name as the building and one small one here designated as Room B in the Departmental Auditorium. This building is on Constitution Avenue between 12th and 14th Streets. Some sessions will be in another Government building, the Commerce Auditorium on 14th Street between Pennsylvania Avenue and Constitution Avenue. These halls which have been provided by the Government for the free use of the Society, are all within easy walking distance of the official hotels (Willard and Raleigh); but considerably farther away are the National Bureau of Standards and the National Academy of Sciences. Buses marked L2 and L4, which start from 13th Street and Pennsylvania Avenue, N.W., usually take about 30 min to reach the Bureau.

Last-minute correspondence to officers of the Society, to chairmen of sessions, and to members generally should be addressed in care of the Chairman of the Local Arrangements Committee, Rooms 107–108, Willard Hotel, Washington, D. C.

All of the members of last year's Local Committee have found themselves possessed of the stamina and the good will necessary to resume their burdens, and the roster is accordingly again R. D. Huntoon, *Chairman;* D. F. Bleil, W. C. Hall, A. I. Mahan, J. H. McMillen, Paul L. Reid, S. F. Singer, L. Slack, G. M. Temmer, and W. R. Tilley, Hereto should be added Dr. Huntoon's secretary, Mrs. Florence Sharkey, and probably other secretaries. This is the sixth year of Dr. Huntoon's able management of our Washington meetings.

Hotel. Room reservations, as urged in a previous issue of this Bulletin, are to be made by writing to the Willard Hotel, Washington 4, D. C. After its accommodations are filled, applicants will be "roomed" at the Raleigh and Ambassador Hotels. More rooms will be available at the Willard on Thursday, April 30, than on Wednesday, April 29, Therefore, if you can conveniently arrive on Thursday morning, do so, and, if you must arrive on Wednesday, write immediately to the hotel. *In any case, mention that you are a member of The American Physical Society coming to this meeting.* And even when you have a "confirmed reservation" slip in your pocket, get to the hotel as early in the day as possible, and, if not roomed at once, go back from time to time during the day instead of waiting till evening.

The **registration fee will be two dollars.** We need the money as our meetings swell.

The **main registration desk** will be located in the Caucus Room on the first floor of the Willard Hotel, and an **ancillary desk** in Conference Room A of the Departmental Auditorium. Only at the former will you find the blackboards with notices of messages and of post-deadline papers and anything else that may be or seem important. Banquet tickets will be sold at both.

Invited papers are fewer than last year, and fewer than we should like, because of a circumstance which will be specified later and may be divined in advance. There are, however, several of very special character.

In memory of the late and great **Ernest Orlando Lawrence,** two speeches will be given on the **history of the cyclotron,** the first by M. Stanley Livingston, his first collaborator, the second by E. M. McMillan, his successor in the directorship of the laboratory known now as the Lawrence Radiation Laboratory. These are scheduled for Friday morning, and on Friday afternoon there will be four

invited papers on as many of the accelerators envisaged for the future. The speeches of the morning will be preceded by a lecture by the first Dannie Heineman prizewinner.

The **Dannie Heineman Prize for Mathematical Physics** has been endowed by the Heineman Foundation for Research, Educational, Charitable and Scientific Purposes, Inc. The gift is administered by The American Institute of Physics, and the choice of the prizewinner is made by a Committee appointed by the Council of The American Physical Society. Five such prizes to be awarded at two-year intervals have been endowed, and the first prizewinner has just been chosen. The first award will be presented at the banquet to Murray Gell-Mann of the California Institute of Technology, and he will give his lecture at 9:45 on Friday morning under a title later to be announced.

A **Symposium** entitled "Precise Neutron Cross Sections" will be held on Thursday afternoon (Session EA).

Our **Division of Fluid Dynamics** will hold a half-day symposium on the Saturday morning (Session VA).

A **three-half-day symposium** entitled "Problems of Space Exploration" was organized by the National Academy of Sciences and the National Aeronautics and Space Administration ("NASA"), and our Society was given the opportunity of co-sponsoring it and of providing a member (Bruno Rossi was chosen) of its organizing Committee. It figures in this Bulletin as the ensemble of Sessions AA, DA, and E, and its location is the National Academy of Sciences at 2101 Constitution Avenue.

Other invited speakers comprise Nicolas Cabrera, George R. Harrison, D. F. Hebbard, K. L. Herzfeld, H. D. Holmgren, L. W. Jones, J. Karle, L. Madansky, J. A. O'Keefe, Howard Reiss, Laura M. Roth, R. E. Schreiber, Richard Wilson, and J. N. Zemel.

Contributed papers. It is a singular fact that sometimes one or more of our meetings will remain of nearly constant size for several years in succession and then will take a sudden upward bound. One of these discontinuities has just come to the Spring Meeting. In the five latest years the numbers of contributed papers were 406, 393, 394, 408, and 404: this time we have 453! It is obvious that plasma physics and cosmic rays have gained in favor, and any physicist can guess the reasons. Other subjects have gained over 1958 and still others have lost, and a careful analysis would take more time than it is reasonable to spend while the Bulletin is being prepared for press. It is this leap in the number of ten-minute papers that has stinted the invited part of the programme. We could have hired additional halls, but it becomes questionable whether due honor is paid to a physicist by inviting him to suffer the competition of more than six simultaneous sessions. Some of the sessions are too long. Some begin at odd times because we must evacuate certain halls at 5 P.M., and on Friday at 4:30 P.M.

The distribution of papers among the six sessions entitled "Theory" was done by Robert Serber, and that for Sessions AB, F, J, NA, SA, and X mainly by the Deputy Secretary.

As some people are prejudiced against Saturday afternoon, it receives no topic which was thus located at either the 1958 Washington or the 1959 Annual Meeting.

The **banquet of the Society** will be held on Friday evening in the Grand Ballroom of the Willard Hotel. Our after-dinner speaker will be the Honorable Lewis L. Strauss, Secretary of Commerce. The Dannie Heineman Prize (see above) will be awarded at this banquet. The banquet is set for 7:30 P.M., and cocktails will be served in the same room from 6:30 P.M. Your ticket priced at $5 will cover both the cocktails and the dinner, but the former will not be available for those who do not pay for the latter. The earlier you buy your tickets, the better it will be for you and for the management. Better get them when you register, and register on Thursday.

The American Institute of Physics announces a book exhibit in the "Cabinet Room" of the Willard Hotel from 9 to 6 on Thursday and Friday, from 9 to noon on Saturday. "All of the major book publishers will be represented and everyone is cordially invited to visit."

The American Institute of Physics will conduct a **Placement Service Register** at the Willard Hotel, April 30 and May 1, 1959. The Register will be open from 9 A.M. to 6 P.M., Thursday and Friday only.

Tea. The National Bureau of Standards will be host at a tea from 4:30 to 6:30 P.M. on Thursday afternoon, in the Manse on the grounds of the Bureau.

Ladies' Programme. Two interesting tours have been arranged for the Ladies' Programme by the Ladies' Entertainment Committee, both of them scheduled for Friday, May first. The long trip is a bus trip to Annapolis, with luncheon at the famous old Carvel Hall Hotel. After the luncheon, the Ladies will be received at "Government House," the traditional home of the Governors of Maryland, by Mrs. J. Millard Tawes, wife of the Governor of Maryland: she has generously opened her home for this occasion. The other tour is of the National

Gallery of Art in Washington itself; after the tour there will be a luncheon for the ladies at the Cosmos Club.

The Annapolis trip costs five dollars altogether; the National Gallery tour, two dollars and a half for the luncheon (admission to the Gallery is free). Advance reservation *must* be made for either, and the reservation and check must be received not later than Monday, April 27th, by the Chairman of the Committee who is Mrs. A. G. McNish. The precise address to be used is: Mrs. A. G. McNish, Room 304, The Manse, National Bureau of Standards, Washington 25, D. C.

The **Council of The American Physical Society** will meet at 10:30 A.M. on Wednesday, April 29, in Conference Room C in the Departmental Auditorium, unless contrary notice is given to its members by special message.

The **Nominating Committee** of the American Physical Society will meet at 4:00 P.M. on Thursday, April 30, in Conference Room C in the Departmental Auditorium, unless contrary notice is given to its members by special message. This Committee consists of J. W. Beams, *Chairman;* W. P. Allis, C. D. Anderson, H. H. Barschall, H. R. Crane, S. A. Goudsmit, Conyers Herring, Henry Hurwitz Jr., and A. M. Weinberg.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special significance, will be considered for admission to the programme if the abstracts are received at the office of the Society not later than Friday, April 24. The titles of such papers as may be accepted will be written on a blackboard near the main registration desk. Part of Session GA has been reserved for them, but it is not impossible that some may be placed elsewhere.

Prospective meetings and deadlines of the Society are listed on page 309 of this Bulletin, and on page 301 appear preliminary announcements of the 1959 Summer Meetings in the East (Milwaukee) and in the very far West (Honolulu).

Your attention is directed to the announcements on **topical conferences** on page 302.

Instructions for the preparation of abstracts are printed on page 309 of this Bulletin. Members should make a habit of re-reading these every time they appear, as they occasionally change and always in the direction of greater stringency.

Errata pertaining to abstracts in this issue will be published in a later issue of this Bulletin if received not later than Monday, May 4, by Miss Ruth Bryans, American Institute of Physics, 335 East 45th Street, New York 17, New York. Do not send in the abstract with erasures and corrections. Write out your corrections in the form "Instead of . . . read . . . ." Add nothing.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

EPITOME OF THE 1959 SPRING MEETING

(Personal names are those of invited speakers.)

Wednesday Afternoon

2:00 AA. Problems in space exploration, I: Whipple, Gold, Parker, Van Allen, Christofilos Academy.

Thursday Morning

10:00 A. Various nuclear topics. Departmental.
9:30 AB. Nuclear forces; energy levels of light nuclei. Congressional.
10:00 B. General physics. Grand Ballroom.
10:00 BA. Upper atmosphere; cosmic rays, I. Commerce.
10:00 C. Cryogenics, I, mostly superconductivity. South Ballroom.
10:00 CA. Solid-state physics, mostly nonmetals. Bureau, East.
9:30 D. Theory, I: weak interactions. B in Departmental.
9:00 DA. Problems in space exploration, II: Newell, Kuiper, Urey, de Vaucouleurs. Academy.

Thursday Afternoon

2:00 E. Problems in space exploration, III: Friedman, Goldberg, Townsend, Jastrow. Academy.
2:00 EA. Symposium on precise neutron cross sections: Weinberg, Havens, Bollinger, Macklin. Departmental.
1:45 F. Nuclear reactions, I, including Coulomb excitation and fission. Congressional.
1:45 FA. Electron physics; plasma, I. Grand Ballroom.
2:00 G. Cosmic rays, II, mainly primaries. Commerce.
2:00 GA. Cryogenics, II: liquid helium. Post-deadline papers, if any. South Ballroom.
1:45 H. Magnetism and ferroelectricity. Bureau, East.
2:00 HA. Theory, II: statistical. B in Departmental.

Friday Morning

9:15 J. Neutron interactions with solids and liquids; neutron capture. Congressional.
9:15 JA. Plasma, II. Grand Ballroom.
9:15 K. Electric dipole moments; magnetic resonance, I. Commerce.
9:30 KA. Wilson; elastic scattering of elementary and other particles. South Ballroom.
9:30 L. Cabrera, Karle, Herzfeld, O'Keefe. Bureau, East.
9:15 M. Theory, III: nuclear. B in Departmental.
9:30 MA. Gell-Mann (Heineman lecture), Livingston, McMillan (Lawrence memorial). Departmental.

Friday Afternoon

2:00 N. Symposium on accelerators of the future: Green, Symon, Panofsky, Livingston. Departmental.
1:45 NA. Fast neutrons. Congressional.
1:45 P. Schreiber, Madansky, Holmgren, Hebbard. Grand Ballroom.
1:45 PA. Magnetic resonance, II. Commerce.
1:45 Q. Harrison; line spectra and x-rays. South Ballroom.
2:00 QA. Solid-state physics, mostly metals. Bureau, East.
2:00 R. Theory, IV: high-energy scattering. B in Departmental.

Friday Evening

7:30 Banquet of The American Physical Society (cocktails from 6:30). After-dinner speaker, The Honorable Lewis Strauss, Secretary of Commerce. Willard, Grand Ballroom.

Saturday Morning

9:00 S. Accelerators and other nuclear apparatus; Jones. Grand Ballroom.
9:30 SA. Neutron spectroscopy. Congressional.
9:00 T. Muons and pions. Departmental.
9:30 TA. Solid-state theory. Bureau, East.
9:15 U. Radioactive nuclei, I. South Ballroom.
9:00 V. Theory, V: quantum theory, general. B in Departmental.
9:30 VA. Symposium of Division of Fluid Dynamics: Grad, Alpher, Malkus, Klebanoff. Commerce.

Saturday Afternoon

1:30 W. Reiss; fluid dynamics. Commerce.
1:30 WA. Roth, Zemel; irradiation effects. Departmental.
1:30 X. Nuclear reactions, II. Congressional.
1:30 XA. Strange particles. Grand Ballroom.
1:30 Y. Molecular spectra. Bureau, East.
1:30 YA. Radioactive nuclei, II. South Ballroom.
1:30 Z. Theory, VI: relativity. B in Departmental.

PROGRAMME

WEDNESDAY AFTERNOON AT 2:00

National Academy of Sciences

(BRUNO ROSSI presiding)

Symposium on Problems in Space Exploration. I

AA1. Solid Particles in the Solar System. FRED L. WHIPPLE, *Smithsonian Astrophysical Observatory.* (30 min.)

AA2. Plasma and Magnetic Fields in the Solar System. THOMAS GOLD, *Harvard College Observatory.* (30 min.)

AA3. Extension of the Solar Corona into Interplanetary Space. EUGENE PARKER, *University of Chicago.* (30 min.)

AA4. The Argus Experiment. N. CHRISTOFILOS, *University of California, Livermore.* (30 min.)

AA5. Particle Populations in the Vicinity of the Earth. JAMES VAN ALLEN, *Iowa State University.* (30 min.)

Round-Table Discussion

J. A. SIMPSON (*Chairman*); speakers of this session, BRUNO ROSSI, A. R. HIBBS, ROBERT JASTROW.

THURSDAY MORNING AT 10:00

Departmental Auditorium

(M. S. LIVINGSTON presiding)

Various Nuclear Topics

A1. On the Importance of the Number Two for Nuclei and Elementary Particles. ENOS E. WITMER, *University of Pennsylvania.*—The writer has pointed out many times before that the electron rest mass m is the natural unit of mass for elementary particles and nuclei both in the ground state and excited states. In terms of this unit a surprising number of nuclei have mass numbers (M) that are integers or astonishingly close to integers, as for example Li^7 and C^{12}. Using this idea it was inferred that m is 0.000548771021 amu. Now I have found that the M values, the nuclear magnetic moments in nuclear magnetons, the fine structure constant, and presumably all nuclear invariants in suitable units have remarkable properties when expressed in the binary scale of numbers. In other words these invariants can be expressed by an algebraic sum of a smaller number of positive and negative powers of 2 than expected by chance. Thus α^{-1} is $(2^7+2^{-7}+2^3+2^{-5}+1)$. The M for He^4 is $(57\times2^7-2+9\times2^{-7})$. In general for a nucleus with A nucleons M is $(14.25\times2^7A+B)$, where B itself is a positive or negative number with remarkable properties. B is small when A is small. For $122\leqslant A\leqslant 203B$ is very approximately -3×2^7. Note also parity, spin, and isotopic spin.

A2. Some Regularities Concerning Second-in-Abundance Isotopes. N. EFREMOV, *1061 Intervale Ave., New York 59, New York.*—The regularities which we observe in relation to the magnitudes of the mass differences between the atomic weights of isotopes which are second in abundance can be formulated in this way: (1) The magnitudes of the mass differences between the atomic weights of second-in-abundance isotopes of successive series of natural elements (e.g., H, He, Li, etc.) are not more than 10 or less than -3. (2) These mass differences are represented by primes (positive integers) such as 2, 3, 5, 7 and 1 and -1, as well as by composite numbers such as 4, 6, 8, 9, 10. But the numbers 1, 3, and 5, prevail here as well as in the case of the chief isotopes.[1] In some cases the sums of the mass differences between the atomic weights of the chief isotopes and those between atomic weights of the second-in-abundance isotopes of the elements of inert-gas (He,Ne,A) periods are equal, e.g.,

Ne period

Elements	Ne	Na	Mg	Al	Si	P	S	Cl	
Chief isotopes	20	23	24	27	28	31	32	35	
Mass differences	3	1	3	1	3	1	3		
Second isotopes	22		26		29		34	37	=15
Mass differences	4		3		5		3		=15

[1] N. Efremov, Bull. Am. Phys. Soc. Ser. II, 4, 102 (1959).

A3. Large-Angle Radiative Electron Scattering at 58 Mev.* P. D. RANDOLPH† AND J. H. FREGEAU, *University of Michigan.*—58-Mev electrons have been scattered from foils of aluminum, tin, and gold (0.034, 0.064, 0.048 g/cm²). The continuum of electrons scattered inelastically through 90° with energies down to 18 Mev were analyzed with a 90° magnetic spectrometer and detected by a Čerenkov counter. The experimental cross sections were measured and compared with the theory of McCormick, Keiffer, and Parzen which is based on the point nucleus bremsstrahlung theory of Bethe and Heitler. The experimental cross sections are lower than predicted by this theory, with the discrepancy becoming larger with increasing scattered electron momentum. The ratio of the experimental cross section to the theoretical decreases to approximately 0.2 for gold and 0.3 for tin for scattered electrons of 55 Mev. For aluminum the effect is not so clearly indicated. Estimates were made of the effect of finite nuclear size on the theoretical cross sections using Born approximation form factors for a uniform nuclear charge distribution. These indicate that the momentum dependence of the experimental cross sections can be attributed to the effect of finite nuclear size.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

† Now at Phillips Petroleum Company, Idaho Falls.

A4. Positronium Decay in Molecular Substances. WERNER BRANDT, *Du Pont Radiation Physics Laboratory*, S. BERKO* AND W. W. WALKER, *University of Virginia*.—The overlap of the Swiss-cheese wave function of positronium (Ps) in dense molecular substances with the lattice wave functions determines the 2γ annihilation rate of positrons bound in *ortho-Ps* via electron pickup (τ_2 decay), and part of the 2γ angular correlation. Consequently, Ps can be considered as *the elementary free radical*. It acts as a chemically nondestructive probe for studying the dependence of radical-molecule interactions on atomic and structural lattice parameters. To explore the sensitivity of this probe, the Ps wave function in an idealized molecular lattice was calculated by the scattering-matrix method and the dependence of τ_2 decay on the lattice parameters investigated. This dependence was tested experimentally by τ_2 measurements on several carefully characterized molecular substances in liquid, crystalline, and glassy states. The data qualitatively confirm the predicted effects due to changes in lattice dimensions and the accompanying changes in molecular valence states. Quantitative details suggest that the appearance of the narrow component in the 2γ angular correlation is caused mainly by changes in the overlap of the Ps and lattice wave functions.

* On leave of absence; present address: Institut for teoretisk fysik, University of Copenhagen, Copenhagen, Denmark.

A5. Positron Annihilation in Alkali Halides. N. K. POPE AND A. T. STEWART, *Chalk River Laboratories*.—The angular correlation of photons from positrons annihilating in two series of alkali halides (LiCl, NaCl, KCl, RbCl, CsCl, and NaF, NaCl, NaBr, NaI) has been measured. The data for NaCl, KCl, and RbCl are practically identical and the data for LiCl and CsCl show slightly greater angular spread. The sodium halide data show a monotonic decrease in angular width from NaF through NaI. Since it is impossible to transform the data to yield the "wave function products" for the annihilation process without making assumptions about the relative amounts and forms of the s-type and p-type electron functions, we have assumed various forms for this product and have compared their transforms with the data. The only form of product function investigated which gave good fits to the data was one in which analytical representations of Hartree-Fock free ion wave functions were used for the negative ion electrons and the positron wave functions were assumed to be centered on the halide ions and to be proportional to $\exp[-\beta^2(r-b)^2]$. For LiCl and CsCl the Gaussian parameters are found to be $\beta=0.475$, $b=2.9$ au; for NaF the parameters are $\beta=0.51$ and $b=2.65$ au. With these values of the parameters most of the annihilations take place with the s-type electrons of the outermost shell of the halide ions.

A6. Positron Annihilation in Gases with Applied Electric Field.* FELIX E. OBENSHAIN AND LORNE A. PAGE, *University of Pittsburgh*.—A study of positronium formation in several gases has been made with applied dc electric fields ranging from 2 to 30 kv/cm. Two methods have been used to observe the annihilation radiation, (a) angular correlation measurement which records two-quantum events only and (b) pulse-height analysis of two- and three-quantum events. Both modes of detection share a common source of radiation, a gas pressure chamber (1–28 atmos) containing a Na^{22} source. One effect of the electric field is to accelerate those positrons which would ordinarily undergo annihilation against atomic electrons, back into the Ore gap where they may then form additional positronium.[1] This has been studied as a function of electric field and of gas pressure for argon, nitrogen, and oxygen. Dense gases, propane, and sulfur-hexafluoride have also been used. Throughout, reversal of the electric field has been given prominence in order that the work on the asymmetry[2] reported earlier might be extended.

* Work done in the Sarah Mellon Scaife Radiation Laboratory and supported by the Office of Ordnance Research, U. S. Army.
[1] V. W. Hughes, J. Appl. Phys. **28**, 16 (1957).
[2] F. E. Obenshain and L. A. Page, Phys. Rev. **112**, 179 (1958).

A7. Attempt to Observe the $Cl^{37}(\bar{\nu},e^-)Ar^{37}$ Reaction Induced by Reactor Antineutrinos.* RAYMOND DAVIS, JR., *Brookhaven National Laboratory*, AND DON S. HARMER,† *Brookhaven National Laboratory and Georgia Institute of Technology*.—An experiment has been performed to test whether fission product antineutrinos will invert the electron capture decay of Ar^{37} by the reaction $Cl^{37}(\bar{\nu},e^-)Ar^{37}$. Three thousand gallons of carbon tetrachloride were exposed to the high antineutrino flux from a production reactor at the Savannah River plant. The argon-37 was isolated and counted in a low-level counter.[1] The cross section for this process was found to be less than 0.25×10^{-45} cm², a factor of 20 below the cross section calculated assuming neutrino-antineutrino identity. The result is consistent with the principle of lepton conservation. Argon-37 was observed in the experiment produced by cosmic radiation and fast neutrons. The Ar^{37} observed in the experiment can be used to set an upper limit on the product of the solar neutrino flux and the average cross section for the neutrino capture reaction: $\phi\bar{\sigma}<1.1\times10^{-33}$ disintegrations sec^{-1}.

* Research performed in part under the auspices of the U. S. Atomic Energy Commission.
† Present address: Engineering Experiment Station, Georgia Institute of Technology, Atlanta, Georgia.
[1] R. Davis, Jr., "Radioisotopes in scientific research," *Proceedings of the First UNESCO International Conference, Paris, 1957* (Pergamon Press, London, 1958), Vol. 1, p. 728.

A8. Comparison of the Ionization Produced in Air by Alpha Particles near 5 Mev and by Beta Particles. Z. BAY AND P. A. NEWMAN, *National Bureau of Standards*.—The average energy (W) expended to make an ion pair in air by Po^{210} alpha particles (initial energy 5.305 Mev) while the particles are slowed down to zero energy, was redetermined recently and confirmed to be larger (35.15 ± 0.1 ev/ion pair) than W_β in air (33.7 ± 0.3 ev/ion pair). It is of interest to explore the energy dependence for alpha particles in air by relating the ionization produced to a small energy loss at different energies (calling the corresponding quantity w). As a preliminary part of this program, the ionization caused by alpha particles while they are slowed in air from ~5 Mev to ~4.5 Mev was measured. The energy loss was determined on the basis of the Holloway-Livingston range-energy curve as corrected by Jesse and Sadauskis. Our result is $w_\alpha=33.6\pm0.6$ ev/ion pair where the major part of the uncertainty results from the use of the Holloway-Livingston curve. Therefore, within the above uncertainty limits, w_{air} for alphas at about 5-Mev energy is the same as W_{air} for beta particles.

A9. Contribution of Multiple Scattering to the Range Straggling of Protons of 10 and 18 Mev. HANS BICHSEL AND EDWIN A. UEHLING, *University of Washington*.—The straggling observed in range measurements of 10- and 18-Mev protons in various metals[1] differs considerably from the Gaussian shape expected on the basis of energy-loss distribution alone. This difference was presumed to be due to the effects of multiple scattering with a small contribution from nuclear scattering. By applying Moliere's theory of multiple scattering[2] to the protons along the total length of their paths we have obtained the contribution to straggling due to multiple scattering alone. This, then, has been folded into the contribution to straggling due to the statistics of energy loss. Total straggling distributions computed in this way agree with the observed data within about 5%.

[1] Bichsel, Mozley, and Aron, Phys. Rev. **105**, 1788 (1957).
[2] G. Moliere, Z. Naturforch. **39**, 78 (1948); H. Bichsel, Phys. Rev. **112**, 182 (1958).

THURSDAY MORNING AT 9:30

Willard, Congressional Room

(L. CRANBERG presiding)

Nuclear Forces; Energy Levels of Light Nuclei

AB1. Test of Charge Independence.* A. V. CREWE, E. L. GARWIN, B. G. LEDLEY, E. LILLETHUN, AND S. M. MARCOWITZ, *University of Chicago.*—The differential cross sections of the reactions $p+d \rightarrow H^3+\pi^+$ and $p+d \rightarrow He^3+\pi^0$ have been measured to an accuracy of $\sim 10\%$ at laboratory angles between 8° and 13°. The heavy particles from the reaction were analyzed in a magnetic spectrometer followed by a counter telescope. Pulse-height analysis was used to discriminate other particles. Measurements to higher accuracy are planned.

* Research supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

AB2. Binding Energy of the Deuteron.* S. RABOY AND C. C. TRAIL, *Argonne National Laboratory.*—The gamma-ray spectrum from neutron capture by hydrogen has been studied with a scintillation spectrometer with an anticoincidence annulus of NaI(Tl). The energy of the line is compared with the three standard gamma rays of Na^{24} and the Cs^{137}. The response of the spectrometer to the full-energy peak is assumed Gaussian for each radiation and a least-squares fit is made to the data. Four measurements give a value of 2.226 ± 0.003 Mev for the deuteron binding energy. Further measurements are in progress.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

AB3. Three-Body Reactions which Compete with $T(d,n)He^4$.* R. K. SMITH, L. CRANBERG, AND J. S. LEVIN, *University of California, Los Alamos Scientific Laboratory.*—Measurements have been made with deuterons of energies between 4.25 and 6.5 Mev incident on tritium. The resultant zero-degree neutron spectra were studied with time-of-flight equipment. An angular distribution was also observed at 6.0 Mev. The fact that the threshold for production of the low-energy neutrons occurs close to the calculated $T(d;n,p)T$ threshold (3.71 Mev), and that the neutron spectrum changes character close to the calculated threshold (4.99 Mev) for the $T(d,2n)He^3$ reaction, indicates that the low-energy neutrons arise from these three-body reactions rather than from a broad excited state in He^4. This conclusion is further substantiated by the fact that the maximum energy of the low-energy neutron spectrum agrees with the calculated maximum energy of neutrons from the $T(d;n,p)T$ reaction. The values for the cross section at zero degrees for the production of three-body reaction neutrons with laboratory energies greater than 500 kev are as follows: (error ±7%)

Deuteron energy (Mev)	4.00	4.25	4.5	5.0	5.5	6.0	6.5
mb/sterad	1.7	9.1	21	49	79	102	114

These values are considerably higher than those given by Henkel, Perry, and Smith.[1]

* This work performed under the auspices of the U. S. Atomic Energy Commission.

[1] Henkel, Perry, and Smith, Phys. Rev. **99**, 1050 (1955).

AB4. Relative Yields of Neutron Groups from $Li^7(p,n)Be^7$.* P. R. BEVINGTON, G. E. MITCHELL, W. W. ROLLAND, R. M. WILENZICK, AND H. W. LEWIS, *Duke University.*—The ratio of the intensities of the two groups of neutrons from the $Li^7(p,n)Be^7$ reaction, leading to the ground state and the 430-kev state of Be^7, has been measured by a Los Alamos time-of-flight system. Since the forward threshold for the n' group is 2.373 Mev, measurements were made for proton energies in excess of 2.5 Mev. Data were taken at 30° intervals between 0° and 150° for proton energies high enough to produce n' neutrons above the detection threshold of the scintillator (~300 kev). Between 2.8- and 3.6-Mev bombarding energy the yield of the n' group increases slowly with energy and is nearly isotropic in the center-of-mass system. Since the yield of the main group falls with increasing angle, the ratio of the n' to the n intensities grows with increasing angle. At $E_p = 3.4$ Mev, the n' to n ratios are approximately 0.10 at 0°, 0.15 at 30°, 0.25 at 60°, 0.35 at 90°, and 0.50 at 120°. This trend holds also at lower energy, severely limiting the usefulness of this reaction as a neutron source above the n' threshold at back angles.

* Supported by the U. S. Atomic Energy Commission.

AB5. Production of Be^7 by He^4 Bombardment of Light Elements.* G. H. BOUCHARD AND A. W. FAIRHALL, *University of Washington.*—Target elements O, Al, Cu, Ag, Au, and Pb have been bombarded with helium ions of energies up to 43 Mev and a search made for Be^7 fragments. Production of Be^7 is observed to occur in O, Al, and Cu, the cross sections at helium ion energies near 40 Mev being 7.3×10^{-27} cm², 4.7×10^{-28} cm², and 4.0×10^{-29} cm², respectively. No Be^7 is observed at the highest energy for Ag, Au, or Pb targets (cross sections $< 10^{-30}$ cm²). The angular distribution of Be^7 fragments from Al target has been examined, and in the laboratory frame of reference $\frac{2}{3}$ of the Be^7 fragments are emitted within 25° of the direction of the helium ion beam. These fragments are therefore produced by some sort of direct interaction mechanism. In the case of the $Al^{27}(He^4,Be^7)Na^{24}$ reaction, the yield of Na^{24} is one-half that of Be^7, indicating that Be^7 may be produced by more than one mechanism. The reaction $Al^{27}(He^4,2\alpha n)Na^{22}$ has also been observed. At 40-Mev bombarding energy the cross section has been measured to be 2.7×10^{-26} cm².

* Supported in part by the U. S. Atomic Energy Commission.

AB6. Properties of the 7.46-Mev State in Li^7.* WILLIAM B. PARDO, *University of Miami,* AND J. H. ROBERTS, *Northwestern University.*—The angular distribution of tritons from the $Li^6(n,\alpha)H^3$ reaction has been measured for 100-kev and 270-kev neutrons. The $Li^6(n,\alpha)H^3$ reaction cross section has been measured for 270-kev neutrons. The angular distribution in the center-of-mass system for 100-kev neutrons $I(\theta) = (0.072 \pm 0.004) + (0.015 \pm 0.003)\cos\theta + (0.024 \pm 0.012)\cos^2\theta$. For 270-kev neutrons the angular distribution $I(\theta) = (0.051 \pm 0.0030) + (0.016 \pm 0.003)\cos\theta + (0.086 \pm 0.010)\cos^2\theta$. The reaction cross section for 270-kev neutrons $\sigma_{n,\alpha} = 3.7 \pm 0.4$ barns. By using the angular distribution calculation of Peshkin and Siegert[1] the data has been found to be consistent only with the assignment of a total angular momentum $J = \frac{5}{2}$ for the 7.46-Mev state of Li^7. The percentage polarization $f(\theta)$ of the emitted tritons has been estimated to have for 100-kev neutrons a maximum value at 97°. The upper limit of this value is $f(\theta) = 0.65$. For 270-kev neutrons the maximum value would occur at 94° with an upper limit of $f(\theta) = 0.62$.

* Supported by the U. S. Atomic Energy Commission.

[1] M. Peshkin and A. J. F. Siegert, Phys. Rev. **87**, 735 (1952).

AB7. Mean Life of the First Excited State of Na^{23}.* V. K. RASMUSSEN, F. R. METZGER, AND C. P. SWANN, *Bartol Research Foundation.*—Nuclear resonant fluorescent scattering by metallic sodium of the 440-kev γ ray from $Na^{23}(p,p')Na^{23}$ has been observed. Since previous observations have shown that with a solid target the Doppler effect is much less than that expected from the initial nuclear recoil velocities, so that the width and shape of the emission line are not known, a self-absorption measurement must be used to get the mean life. Our preliminary value is $(1.8\pm0.5)\times10^{-12}$ sec, assuming a spin of $\frac{3}{2}$ for the excited state. Using the $E2$ transition probability for this level from Coulomb excitation measurements,[1] the ratio of $E2$ to $M1$ amplitudes is $\delta=0.056$. The calculated angular distribution of the resonance radiation is quite insensitive to changes in δ. For δ positive, the ratio of the intensity for 151° scattering to that for 115° scattering is 1.06, and for δ negative, the ratio is 1.21. Our preliminary experimental value is 1.10 ± 0.04, suggesting that the $E2$ and $M1$ amplitudes have, in the notation of Biedenharn and Rose,[2] the same sign. It may also be noted that this ratio is consistent with spin $\frac{3}{2}$ for the excited state, as well as with the generally accepted value of $\frac{5}{2}$.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Alder, Bohr, Huus, Mottelson, and Winther, Revs. Modern Phys. **28**, 432 (1956).
[2] L. C. Biedenharn and M. E. Rose, Revs. Modern Phys. **25**, 729 (1953).

AB8. Energy Levels of B^9.* A. LEMONICK AND R. G. CORNWELL,† *Haverford College,* AND E. ALMQVIST, *Chalk River Laboratories.*—An isotopic LiCl target on a copper backing was bombarded by 2.34-Mev He^3 particles at Chalk River. Ilford *C*-2 emulsions, 400 μ thick, placed at 10 angles to the incident beam are being used to measure the neutron spectra from the reaction $Li^7(He^3,n)B^9$. Preliminary results at 0° indicate at least 6 resolved neutron groups corresponding to the ground state of B^9 and to levels with excitation energies less than 9 Mev. Scanning is continuing on the 0° plate and on plates at other angles. A comparison will be made with the results obtained[1] on the level structure of the mirror nucleus, Be^9.

* Supported by the National Science Foundation and the Research Corporation.
† Supported by the Haverford College Faculty Research Fund.
[1] Ajzenberg-Selove, Jarmie, and Haddad, Bull. Am. Phys. Soc. Ser. II, **4**, 258 (1959), this issue.

AB9. Direct Radiative Capture of Protons by C^{13}.* E. K. WARBURTON AND W. T. PINKSTON, *Princeton University,* AND H. J. ROSE AND E. N. HATCH, *Brookhaven National Laboratory.*—A nonresonant 3.1-Mev γ ray with an anisotropy of -0.95 ± 0.1 was observed with a cross section of 7 ± 3 μb following bombardment of C^{13} by ~1.40-Mev protons. This γ ray was established as a transition to the $J=1$ N^{14} 5.69-Mev level. The γ-ray intensity was observed to be symmetric about 90°; therefore, the anisotropy cannot arise from interference of an even parity level with the broad 0^- 8.70-Mev level. A transition was also observed to the N^{14} (0^-) 4.91-Mev level with an anisotropy of -0.5 ± 0.3 (with an additional uncertainty due to the possible presence of unresolved γ rays). These results indicate that the N^{14} 5.69-Mev level has odd parity and that the anisotropy of the 3.1-Mev γ ray is due to radiative capture of p-wave protons into an s state as has been observed in $C^{12}+p$ and $O^{16}+p$, and for which a $\sin^2\theta$ distribution is expected. The ratio of the capture cross sections into the 5.69- and 4.91-Mev levels was measured to be 1.8 ± 0.6, in agreement with the ratio of 1.53 expected for the capture mechanism if the N^{14} 5.60- and 4.91-Mev levels are 1^- and 0^- and have equal $2s$-reduced widths for the C^{13} ground state as parent.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

AB10. 9.18-Mev Level in N^{14}.* R. W. KRONE, J. J. SINGH, AND F. W. PROSSER, JR., *University of Kansas.*—A recent polarization experiment[1] in this laboratory indicates that the 9.18-Mev gamma ray produced in the $C^{13}(p,\gamma)$ reaction at 1.75 Mev is either $M1$ or $E2$ in character. Previously[2] this transition, because of its larger radiation width, has been regarded as $E1$ and the resonance level spin 2^-. This spin assignment has been used in fixing the 6.44-Mev level as 3^+. But if the resonance level is $(1,2)^+$, then the 3^+ assignment to the 6.44-Mev level will be questionable. We have made some further measurements on this reaction. The results and their interpretation will be reported.

* This work has been supported in part by the U. S. Atomic Energy Commission.
[1] Strassenburg, Hubert, Krone, and Prosser, Bull. Am. Phys. Soc. Ser. II, **3**, 372 (1958).
[2] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **27**, 127 (1955).

AB11. Low Lying Levels in O^{19} from the $O^{18}(d,p)O^{19}$ Reaction.* W. WILLIAMS, JR., AND P. V. C. HOUGH, *University of Michigan.*—Proton groups have been observed for five O^{19} levels: the known† ground level ($Q=1.730$ Mev) and first two excited levels at 0.096-Mev and 1.470-Mev excitation and two previously unreported levels with preliminary excitation values of 3.14-Mev and 3.94-Mev. The $O^{18}(d,p)O^{19}$ reaction protons are produced by bombarding thin, gold leaf backed, O^{18}-enriched LiOH targets with 7.8-Mev deuterons from the University of Michigan 42-in. cyclotron. These protons are momentum analyzed in a medium resolution magnetic analyzer and are recorded in Kodak NTB nuclear track plates (100-μ emulsion thickness) at the analyzer image plane. The targets are selected so that the target thickness limited resolution of the system is no greater than 40–50-kev. A velocity filter, preceding the analyzer, is used at high (>2.5 Mev) O^{19} excitation to prevent degraded deuterons from scattering through the analyzer at low reaction angles. Most of the nuclear track plates exposed during this study have been scanned by a nuclear emulsion scanner. Results of current angular distribution studies of these low lying O^{19} levels will be given.

* This work has been supported by the U. S. Atomic Energy Commission and by the Michigan Memorial Phoenix Project.
† C. Mileikowsky and K. Ahnlund, Phys. Rev. **96**, 996 (1954).

AB12. Further Investigations of the Interaction of He^3 with C^{12} and Al^{27} in the Energy Region 6 to 24 Mev.* D. R. F. COCHRAN AND J. D. KNIGHT, *Los Alamos Scientific Laboratory.*—In extension of previous work,[1] the excitation functions for the reactions $Al^{27}(He^3,2\alpha)Na^{22}$, $C^{12}(He^3,\alpha)C^{11}$, and $C^{12}(He^3,d$ and $np)N^{13}$ have been determined at He^3 energies from 6.5 to 24 Mev. In addition, a series of integral experiments have been done to determine the excitation function for the $C^{12}(He^3,2\alpha)Be^7$ reaction. Some measurements will also be reported on the $Al^{27}(He^3,\alpha 2p)Na^{24}$, $Al^{27}(He^3,3\alpha)F^{18}$, and $Al^{27}(He^3,2p)Al^{28}$ reactions as has been done previously.[2] The $C^{12}(He^3,\alpha)C^{11}$ and $C^{12}(He^3,d$ and $np)N^{13}$ reactions show resonances at approximately 8.9, 10.1, and possibly 11.9 Mev in addition to the resonance reported earlier at 17.1 Mev.[1] The observed recoil properties of the radioactive fragments will be discussed in terms of possible reaction mechanisms.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] D. R. F. Cochran and J. D. Knight, Bull. Am. Phys. Soc. Ser. II, **3**, 323 (1958).
[2] S. S. Markowitz and J. M. Hall, Bull. Am. Phys. Soc. Ser. II, **4**, 8 (1959).

AB13. Exchange Transfer Reaction $Al^{27}(N^{14},Mg^{27})O^{14}$. J. J. PINAJIAN, *Oak Ridge National Laboratory.**—A search was made for 9.5-min Mg^{27} from Al^{27} bombarded by 25.5-Mev nitrogen ions. This reaction, $Al^{27}(N^{14},Mg^{27})O^{14}$, may be described as a simultaneous transfer of a neutron from one nucleus and a proton from the other. The Q value is -7.8 Mev. Mg^{27} cannot be produced by the evaporation of light particles as in $Al^{27}(N^{14},3\alpha 2p)Mg^{27}$ since the Q is -21.6 Mev and the available energy is only 16.8 Mev. A second Al foil

behind the target was used to determine the amount of Mg^{27} formed from $Al^{27}(n,p)Mg^{27}$ due to neutrons produced in the target. Mg^{27} was chemically separated and thick target yields were measured by absolute beta counting. In further experiments the 0.84-Mev and 1.02-Mev gamma rays from Mg^{27} were detected with a scintillation spectrometer. The number of incident nitrogen ions was determined from the amount of K^{38} formed in the target. Previously its yield from the reaction $Al^{27}(N^{14},p2n)K^{38}$ was found to be 3.8×10^{-8}/nitrogen ion. The yield of Mg^{27}/nitrogen ion is 1.03×10^{-11} and 1.04×10^{-11} from beta and gamma measurements, respectively. The energy is just barely above the Coulomb barrier. Assuming that its excitation function is not very different from a neutron transfer reaction in Al, the cross section for the exchange transfer is $2.3(+2.0, -1.0)\cdot10^{-30}$ cm^2.

* Operated for U. S. Atomic Energy Commission by Union Carbide Corporation.

AB14. Excitation Curve of Gamma Rays Produced by Protons on Fluorine.* C. C. TRAIL AND S. RABOY, *Argonne National Laboratory.*—The yield of 6.1-, 6.9-, and 7.1-Mev gamma rays of O^{16} from the (p,α) reaction on F^{19} has been studied as a function of bombarding energy. The scintillation spectrometer with an anticoincidence annulus of NaI(Tl) was used as a gamma-ray detector. The ratio of the intensity of the 7-Mev gamma ray to the intensity of the 6-Mev gamma ray was determined as a function of bombarding energy. Angular distributions of the gamma rays of O^{16} will be presented. The results of studies of gamma rays of F^{19} excited by inelastic scattering of the protons will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

AB15. Inelastic Scattering of Protons from Mg^{25}.* G. SCHRANK AND E. K. WARBURTON, *Princeton University.*—Inelastic scattering of 17-Mev protons by Mg^{25} has been studied. Proton groups were observed corresponding to excitations in Mg^{25} of 1.6, 2.8, 3.4, and 4.0 Mev. The differential cross sections as a function of angle between 15° and 170° lab were obtained for these four groups. The groups at 1.6 and 3.4 Mev correspond to known levels of Mg^{25}, while the groups at 2.8 and 4.0 Mev may well contain contributions from several unresolved levels. All four groups peak in the forward direction and do not show any appreciable diffraction structure. The 1.6-Mev group is excited most strongly and appears to contain considerable $l=0$ contribution. Groups corresponding to the known 0.6 and 1.0 levels in Mg^{25} were not seen. This absence is expected from the collective model.

* This work was supported by the U. S. Atomic Energy Commission and The Higgins Scientific Trust Fund.

AB16. Gamma-Ray Activation of Pr^{141} and Cu^{63}.* L. D. COHEN AND W. E. STEPHENS, *University of Pennsylvania.*—Direct measurements of the $Pr^{141}(\gamma,n)Pr^{140}$ and $Cu^{63}(\gamma,n)Cu^{62}$ reaction cross sections have been made at 20.5 Mev using the monochromatic gamma ray from the $T(p,\gamma)He^4$ reaction. The ratio of the $Pr^{141}(\gamma,n)$ to $Cu^{63}(\gamma,n)$ cross sections is approximately two to one. Using the value for Cu of 45 mb at 20.5 Mev from the curve of Berman and Brown,[1] the $Pr^{141}(\gamma,n)$ cross section would be approximately 100 mb. This value is in contrast to the one reported by J. Goldemberg[2] of less than 10 mb, and in agreement with Carver and Turchinetz[3] who report a value of 84–90 mb at 20.5 Mev for $Pr^{141}(\gamma,n)$. Measurements are continuing and it is hoped a firmer value will be ready in the near future.

* Supported by the joint program of the U. S. Atomic Energy Commission and the Office of Naval Research and by the National Science Foundation.

[1] A. I. Berman and K. L. Brown, Phys. Rev. **96**, 83 (1954).
[2] J. Goldemberg, Program of 1958 Photonuclear Conference, Washington, D. C.
[3] J. H. Carver and W. Turchinetz, Proc. Phys. Soc. (London) **73**, 69 (1959).

THURSDAY MORNING AT 10:00

Willard, Grand Ballroom

(K. F. HERZFELD presiding)

General Physics

B1. Comparison between Theory and Observation for the Outer Planets. R. KROTKOV AND R. H. DICKE, *Princeton University.*—The confidence of physicists in the Newtonian theory of gravitation would appear to be based in large part on a presumed perfect agreement between astronomical observations and theory, while it is likely that the confidence of astronomers in the classical theory is based, at least in part, on the confidence of physicists responsible for the basic theories. However, systematic discrepancies between computed and observed orbits do exist.[1] We have analyzed the differences between observations and a numerical integration of the Newtonian equations of motion recently carried out by Eckert, Brouwer, and Clemence[2] for the five outer planets. The autocovariance of these differences for Jupiter over the last 160 years shows that they contain a periodic term with period 12.38 years and amplitude 0.25 second of arc. No presently known source of systematic error would lead to a deviation in Jupiter's longitude with period slightly longer than Jupiter's year (11.86 earth years).

[1] G. M. Clemence, Monthly Notices Roy. Astron. Soc. **111**, 219 (1951).
[2] Eckert, Brouwer, and Clemence, Astron. Papers Am. Ephem. **12** (1951).

B2. Hydraulic Failure and the Flow of Blood. HARRY LOBEL.—Both engineering and medicine have to deal with the problem of fluids through branching conduits. In both fields, the point of bifurcation is recognized as a critical area. Failure of the conduit or of the artery at the bifurcation is common and serious. On the other hand, arterial systems in people of 80 and 90 years sometimes retain the characteristics of youth. Is this longevity functional or organic? Can characteristics protecting the arteries from hydraulic stresses have industrial applications? On studying healthy arterial systems, several design features for the prevention of hydraulic stresses were discovered. One example is the structure of the bifurcation itself. The mouths of arteries branching from the aorta are funnel-shaped. Microscopic examination shows the presence of muscle fibers. On stimulation, the renal artery, for example, is seen to adjust its contour to correspond with varying flows of blood. Slight malfunction, on the other hand, results in loss of efficiency and severe hydrodynamic stresses. The design of the arteries suggests that hydraulic systems are constrained systems. Hydraulic systems in which the contour of the conduits is designed to correspond with the rate of acceleration of the fluid have greater efficiency and longer life.

B3. "Reflected" Xenon Ions.* D. S. BEERS† AND R. C. BRADLEY, *Cornell University.*—A true reflection of inert gas ions from a metal surface cannot be understood on the basis of Auger neutralization processes. A preliminary study to determine the origin of "reflexed" xenon ions (platinum target) has been made using an ultra-high vacuum mass spectrometer. Results indicate: (1) the yield of "reflected" ions (defined as the ratio of measured "reflected"-ion current to incident-ion current) is independent of incident-ion energy (100 ev to 1000 ev) and incident-ion current; (2) the "reflected"-ion energy is approximately zero (retarding potential technique); (3) the dependence of the true yield upon target temperature T (30°C to 1280°C) and ambient xenon pressure p (2×10^{-8} to 5×10^{-5} mm) is given approximately by $\gamma=10^{-4}/(1+K_1e^{-K_2/kT})\times(1+B/p)$, where $K_1=53$, $K_2=0.43$ ev, $B=1.5\times10^{-5}$ mm. It is suggested that the incident-ion beam is not actually reflected from the target surface and that the "reflected" ions originate from xenon gas that is absorbed, according to Langmuir's theory of adsorption, on the target surface. Tentative mechanisms will be discussed to account for the adsorption, ionization, and ejection of the xenon atoms.

* Supported by the U. S. Air Force through the Office of Scientific Research of the Air Force Research and Development Command.
† Present address, RCA Laboratories, Princeton.

B4. Kinetic Theory of Heat Flow.* E. P. GROSS, *Brandeis University,* AND S. ZIERING, *Raytheon Manufacturing Company.*—A study is made of the flow of heat between parallel plates of slightly different temperatures. The problem is described by the linearized Boltzmann equation which is subject to microscopic boundary conditions. We approximate the distribution function by half-range polynomials in velocity space and determine the space-dependent coefficients by forming half-range moment equations. An approximation involving four pairs of space functions suffices to give an accurate treatment of the heat flow and of the density and temperature profiles for the entire range of conditions from free molecule to hydrodynamic. Detailed numerical results for the temperature slip and molecular boundary structure are obtained for hard spheres and Maxwellian molecules. The accuracy of cruder half-range approximations and other methods of fixing the coefficients is established. A four-function approximation is used to develop a rough theory of nonlinear heat flow (large temperature difference).

* Research partially supported by U. S. Air Force Office of Scientific Research.

B5. Forced Periodic Changes of Kinetic Energy of Gas Molecules as a Means of Vacuum Measurement. HELMUT SCHWARZ, *Radio Corporation of America, Somerville.*—Gas molecules in a container under low pressure—pressure lower than that attained when the mean free path is equal to or greater than the geometrical dimensions of the container—may impinge on a solid surface, the temperature of which can be made to change periodically. Depending at what time phase they reach this surface, their kinetic energy will vary with the mechanical frequency of a membrane held at constant low temperature. This membrane will vibrate up to large amplitudes when hit by the gas molecules coming from the periodically heated surface. The amplitude is a measure of the gas pressure. If a phase-sensitive lock-in amplifier system is employed, much greater sensitivity can be reached than is possible with the generally used Knudsen-type vacuum gauges. A general solution for the temperature function and the "radiometric" force is given and numerical curves for one example are calculated.

B6. Diffusion in Liquids. DAVID W. MCCALL, DEAN C. DOUGLASS, AND ERNEST W. ANDERSON, *Bell Telephone Laboratories.*—Self-diffusion coefficients have been measured for water, nitromethane, acetone, benzene, cyclohexane, isopentane, and neopentane. Temperature and pressure dependences have been determined for nitromethane, acetone, cyclohexane, and isopentane. The temperature dependence has been determined for neopentane and the pressure dependence has been determined for water and benzene. Plots of $\ln D$ *vs* $1/T$ and $\ln D$ *vs* p are linear except for the pressure plots for nitromethane and isopentane. Activation energies and volumes have been derived from these plots and compared with various theories. The data reported make the complexity of the diffusion phenomenon apparent. The semiempirical modification of the equation of Longuet-Higgins and Pople, which enjoyed some success in describing results for the paraffin hydrocarbons, is shown to be unsatisfactory.

B7. Diffusion Model for the System P_2O_5-SiO_2-Si. C. T. SAH, H. SELLO, AND D. A. TREMERE, *Shockley Transistor Corporation.*—The diffusion of phosphorus from a P_2O_5 vapor phase into (a) silicon oxide films or (b) into silicon through silicon oxide films is discussed using a diffusion model. Case (a) corresponds to the diffusion of an oxide of phosphorus through a compound or glass composed of ($x SiO_2 \cdot y P_2O_5$). The glass is formed by a rapid chemical reaction between SiO_2 and P_2O_5 at the interface of the glass and SiO_2. Thus the interface advances at a velocity which is limited by diffusion. Case (b) corresponds to a two-layer diffusion with a small segregation coefficient of phosphorus between the glass and silicon. The over-all model accounts completely for the experimental results.[1] Important predicted and experimental observations are (1) a parabolic growth law of the total glass thickness, (2) a rapid transition from partial masking to complete masking within an oxide layer thickness of less than 0.05 μ, and (3) a region of linear dependence of the silicon n-p junction depth on the oxide thickness.

[1] Sah, Sello, and Tremere, Bull. Am. Phys. Soc. Ser. II, **4**, 157 (1959).

B8. Isotopic Thermal Diffusion Ratios for Helium, Neon, and Argon at Low Temperatures.* JOSEPH G. KELLEY AND W. W. WATSON, *Yale University.*—A sensitive check on the force law between molecules is provided by measurement of the variation of the thermal diffusion ratio R_T with temperature, since thermal diffusion is a second-order effect. Low-temperature data are the most useful for matching theory and experiment because the R_T *vs* $\bar{T}$ curves are rising sharply with increasing T in this region. This is a continuation of the work of Moran and Watson,[1] but with an all-glass "trennschankel" with 19 separation tubes, especially designed for use at low temperatures. The lower portions of the tubes were cooled by immersion either in liquid nitrogen or a Dry Ice-acetone mixture. With the earlier data, we now have R_T values for these gases from 170°K to 650°K. Argon ($R_T=0.077$ at $\bar{T}=167$°K) is best fitted by a modified Buckingham potential (exp 6, $\alpha=15$, $\epsilon/k=154$°K). Neon ($R_T=0.347$ at $\bar{T}=171$°K) is best fitted by a modified Buckingham potential (exp 6, $\alpha=14$, $\epsilon/k=70$°K). The helium data ($R_T=0.376$ at $\bar{T}=170$°K) cannot be fitted by either a modified Buckingham or an L-J potential. This interesting situation for helium will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.
[1] T. I. Moran and W. W. Watson, Phys. Rev. **109**, 1184 (1958).

B9. Electron Diffraction Studies of Thin Films of α-Nitrogen. E. M. HÖRL, *National Bureau of Standards.*—Nitrogen gas was condensed on Formvar and polycrystalline aluminum substrates at temperatures of 4°K and 20°K and investigated by the transmission diffraction technique. At these temperatures the structure of the deposited films was studied as a function of the deposition condition (gas flow rate and time of deposition). No preferred orientation of the microcrystallites could be observed in any case, but considerable

faulting seems to occur in the stacking of the (111) planes in deposits at 4°K. This phenomenon caused changes in the diffraction pattern, which were similar to those observed previously on minute silver crystallites with stacking faults by K. Kimoto.[1] Furthermore, investigations were made on the change of the film structure caused by electron bombardment. As an effect of the bombardment, a temperature gradient was produced over the specimen surface causing a preferred crystal growth [(111) planes ⊥ temperature gradient].

[1] K. Kimoto, J. Phys. Soc. Japan **8**, 762 (1953).

B10. Structure in Perfluorocarbon-Hydrocarbon Solutions. G. W. BRADY, *Bell Telephone Laboratories* (introduced by M. Tanenbaum).—Investigation of the small-angle x-ray scattering from solutions of perfluoroheptane-isooctane show that there is a large degree of clustering of one or the other species in the solutions. The experiments were done at 28.3°C. At 10 mole % perfluoroheptane the clusters have a radius of ~10 A as determined from Guinier plots. The radius increases with perfluorocarbon concentration reaching a value of ~35 A at 40% perfluoroheptane. At 50%, interference peaks become evident, indicating considerable interaction between the clusters, possibly of the excluded volume type. At higher concentrations the clusters decrease in size, and it appears that there is a phase reversal; that is, at low perfluorocarbon concentration the clusters consist of perfluorocarbon and at high (perfluorocarbon) concentration, the clusters are made up of hydrocarbon molecules.

B11. First-Order Phase Transitions in *n*-Paraffins at Elevated Pressures.* R. R. NELSON, W. WEBB, AND J. A. DIXON, *Pennsylvania State University.*—High-purity *n*-nonane, *n*-dodecane, *n*-tridecane, *n*-pentadecane, *n*-octadecane, and *n*-tetracosane were frozen by being subjected to hydrostatic pressures up to ten kilobars at seven temperatures ranging from 15.56°C to 135.00°C. A single polymorphic phase transition was observed in all but *n*-dodecane and *n*-octadecane. In all cases, the transition temperature increased with pressure, the increase being slightly more rapid for the even *n*-paraffins. The melting temperature of an even *n*-paraffin is lower than that expected from interpolation of the melting temperatures of the adjacent odd ones; this effect increases with pressure and decreases with molecular length. Specific volume changes associated with transitions from the most dense solid to the liquid phase were the same for the *n*-paraffins of the same species (odd or even) at the same pressure, the changes being smaller for the odd ones. The liquid specific volumes at the same freezing pressure were nearly the same for at least three of the *n*-paraffins investigated.

* Work supported in part by the American Petroleum Institute.

THURSDAY MORNING AT 10:00

Commerce Auditorium

(S. F. SINGER presiding)

Upper Atmosphere; Cosmic Rays, I

BA1. Distribution of Neutral Hydrogen in the Earth's Exosphere.* S. F. SINGER, *University of Maryland.*—The exosphere is defined as the outermost region of a planetary atmosphere where collisions can be neglected and neutral atoms move in essentially free ballistic orbits. We derive their concentration as a function of altitude; it differs considerably from densities obtained by considerations of thermodynamic equilibrium. The new theory gives the correct value for the escape flux and for the density at infinity. We can now obtain numerical values for the lower exosphere of the earth by applying a theory of the cosmic-ray radiation belt[1] to counting rates observed in satellites by Van Allen *et al.* Combining with drag data from satellite orbits, we obtain a temperature of 1500°K at 530 km, the deduced base of the exosphere. The transition altitude (beyond which hydrogen takes over from oxygen as the most important constituent of the exosphere) turns out to be 1000 km. At this level the H concentration is 3×10^{8} per cm³ and the *total* density 9×10^{-18} g per cm³. Numerical results will be presented on neutral hydrogen densities out to several earth radii.

* Assisted by the Air Force Office of Scientific Research.
[1] S. F. Singer, Phys. Rev. Letters **1**, 171, 181 (1958).

BA2. Ionospheric Heating by Hydromagnetic Waves. A. J. DESSLER, *Lockheed Aircraft Corporation.*—The rate of energy dissipation per unit volume is investigated for hydromagnetic waves traveling downward through the ionosphere. A calculation of the heating rate is made, based on assumptions as to the amplitude and Fourier spectrum of the hydromagnetic waves.[1] It is argued in a general way that the peak heating rate due to hydromagnetic waves occurs near 175 km. The results, which are strongly dependent on the assumed values for the amplitude and Fourier spectrum of the hydromagnetic waves, indicate that hydromagnetic heating is normally not important in determining the temperature in the *F* region. However, during a magnetic storm, the hydromagnetic heating rate may become the dominant source of heat in the *F* region. The suggestion is made that the observed lifting of the *F* region during a magnetic storm is due to an increased heating rate caused by the storm generated hydromagnetic activity. It is shown that it is not possible to account for the main phase of a magnetic storm by ionospheric heating.

BA3. Observations of the Geomagnetic Field at Great Distances: Pioneer I. C. P. SONETT, D. L. JUDGE, J. M. KELSO, AND A. R. SIMS, *Space Technology Laboratories.*—Examination of the telemetry record of the magnetometer carried on Pioneer I has disclosed numerous amplitude and phase fluctuations in the received signal. The fluctuations which have been noted may be due to a combination of amplitude and rotational changes in the magnetic intensity vector. Several zeros coupled with gross changes of phase appear in the data. These indicate the possibility of a rotation of the *H* vector through the spin axis of the vehicle. In addition, several short bursts of almost periodic (8 to 12 sec) amplitude fluctuations appear in the data obtained around 10 earth radii. The possibility that these fluctuations are related to the geomagnetic-coronal boundary[1] is being investigated. Utilizing Dessler's[2] attenuation coefficient for hydromagnetic disturbances propagated through the ionosphere, micropulsations of about 1 μ-oersted recorded at Palo Alto are in accord with the magnitude of fluctuations observed in the vehicle.

Comparison of the mean amplitude of H normal with that predicted from an eccentric dipole model implies an increasing variation with distance.

[1] F. Hoyle, Phys. Rev. **104**, 269 (1956).
[2] A. J. Dessler, J. Geophys. Research **63**, 507 (1958).

BA4. Ionizing Radiation at Altitudes of 3500 to 36 000 km: Pioneer I. P. J. COLEMAN, JR., C. P. SONETT, AND ALAN ROSEN, *Space Technology Laboratories.*—The total ionizing component of cosmic radiation was measured on October 11, 1958, by means of an ionization chamber mounted on the Pioneer I lunar prove vehicle. Data were gathered over an altitude range from 3500 to 36 000 km. The latitude ranged from 35° to 5°N while the data were being taken. An extensive study of the laboratory calibration procedure has been undertaken and an analysis of the telemetered data has been completed. Analysis of the observed data indicates that the following deductions may be made: (1) The radiation level rises to a peak and then drops to a very low level as the altitude increases. This represents the first experimental verification of the existence of a confined radiation zone of the type postulated by Van Allen *et al.*[1] (2) In the altitudes ranging from approximately 4000 to 24 000 km, the radiation level is in excess of 2 roentgens per hour. This result yields a quantitative measure of the depth of the radiation belt in the region of 20°N latitude. (3) In the vicinity of 20°N latitude, the peak of the radiation belt occurs at an altitude of 10 000±2000 km. (4) The maximum radiation level observed is 10 roentgens per hr.

[1] Van Allen, Ludwig, Ray, and McIlwain, IGY Satellite Report Series, No. 3, National Academy of Sciences, National Research Council, Washington 25, D. C., May 1, 1958.

BA5. Ionizing Radiation Detected by Pioneer II. ALAN ROSEN, C. P. SONETT, AND P. J. COLEMAN, JR., *Space Technology Laboratories.*—The lunar probe rocket, Pioneer II, was launched on November 7, 1958. The total ionizing component of cosmic radiation was measured by means of an ionization chamber which was essentially the same as that used in Pioneer I. Data were gathered at north latitudes ranging from 30° to 20° and west longitudes ranging from 35° to 0°, up to an altitude of 1520 km. The observed ionization was less than 0.2 roentgen per hour at altitudes below 1250 km and latitudes less than 30°N. At the apogee of the orbit, while the vehicle maintained an essentially constant altitude of 1500±20 km, the vehicle traversed 7° of latitude. During this time, the ionization was observed to increase at a rate of 0.2 roentgen per degree decrease in latitude. The data which were gathered over the remainder of the orbit of the vehicle will be presented also, and correlations between these data and other observations will be discussed.

BA6. Cosmic-Ray Produced Cl^{36} and Ar^{39} in Iron Meteorites.* ESTHER L. SPRENKEL, *Brookhaven National Laboratory and University of Rochester,* RAYMOND DAVIS, JR., *Brookhaven National Laboratory,* AND EDWIN O. WIIG, *University of Rochester.*—The Cl^{36} activity has been measured in seven iron meteorites for the purpose of determining the cosmic-ray exposure ages; that is the time since the meteorite was formed by fragmentation of its parent asteroidal body. The exposure time may be determined from measurements of the cosmic-ray induced Cl^{36} activity (308 000-yr half-life) and the accumulated Ar^{36} decay product. This method assumes the constancy of the cosmic-ray flux. In order to test this assumption, the Ar^{39} (260-yr half-life) activity in the Sikhote Alin meteorite was compared with the Cl^{36} activity. Several hundred grams of the meteorite were dissolved in acid, the chlorine isolated, and counted in a low-level screenwall counter as solid ammonium chloride. The Ar^{39} was removed from the solution by sweeping with helium, purified, and counted in a low-level G-M counter. Chlorine-36 activities in the range 1.0 to 9.0 dis/min/kg were observed. The Ar^{39} was below detectability (0.01 dis/min/kg) on all meteorites except the Sikhote Alin fall of 1948. From the cross-section ratio for Cl^{36} to Ar^{39}, derived from high-energy spallation data, and the activity ratio for Cl^{36} to Ar^{39}, observed in the Sikhote Alin meteorite, it appears that the cosmic-ray intensity in this meteorite has not varied more than 10% in the last 100 000 years.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

BA7. Hydrodynamic Origin of Cosmic Rays. S. A. COLGATE AND M. H. JOHNSON,* *University of California, Livermore.*—It is suggested that cosmic rays may be generated during supernova explosions by the passage of a shock through the outer layers of the star. The rapid decrease in density more than offsets the divergence so that the shock increases in strength as it passes radially outward. With an initial explosion radius 3×10^8 cm (density 10^8 g/cm^3) and temperature rise to 1 Mev from an ambient temperature 0.5 Mev, the shock becomes relativistic at a radius 2×10^9 cm (density 10 g/cm^3). At this point the material kinetic energy is about 10^3 Mev per nucleon and increases to 10^{11} Mev at a density 10^{-7} g/cm^3 where radiation breaks out of the stellar atmosphere. The integral energy spectrum varies from $E^{-1.3}$ to $E^{-1.7}$ corresponding to density variations as the $\frac{2}{3}$ power or the $\frac{1}{2}$ power of the temperature in solutions of the stellar transport equations. The heavy-element abundances observed in cosmic rays are the same as the abundances expected in the surface layers of highly evolved stars of the supernova type. Finally the fraction of supernova energy transformed to cosmic-ray energy may be of the order of a few percent, which appears sufficient to account for the total energy in cosmic radiation.

* Consultant; affiliated with Aeronutronic Systems, Inc., Glendale, California.

BA8. Cosmic-Ray Tracks in Scintillation Chambers.* G. T. REYNOLDS, R. GIACCONI, AND D. SCARL, *Princeton University.*—Filament chambers have been constructed[1] and used in conjunction with an image intensifier chain. Tracks of cosmic-ray particles have been photographed on Royal X Pan film. One of the filament chambers used was 4 in. long, 1 in. wide, and 1½ in. deep. Requirements on tube gains, background noise, and pulsing techniques will be discussed.

* Supported by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] G. T. Reynolds, Nucleonics **16**, 60 (1958).

BA9. Cosmic-Ray Neutron Energy Spectrum.* WILMOT N. HESS, H. WADE PATTERSON, AND ROGER W. WALLACE, *University of California, Berkeley,* AND EDWARD L. CHUPP, *University of California, Livermore.*—Over the past three years we have made measurements with a variety of neutron detectors at altitudes from sea level to 40 000 ft in order to determine the cosmic-ray neutron energy spectrum. The detectors used in this experiment were a BF_3 counter with and without CH_2 jackets, a polyethylene-lined proportional counter, a gold-foil activation detector, and a bismuth fission ionization chamber. Also used in the analysis were data on stars produced in nuclear emulsion, and on C^{14} production in the atmosphere. From the measured counting rates of the several detectors and the measured absolute counting efficiencies we obtained the spectrum. The energy range covered is from thermal energy to 1 Bev. Over this energy range the omni directional neutron flux has been determined for all altitudes lower than 40 000 ft with an accuracy of about ±30%. One feature of the spectrum that had not been reported earlier is a peak at about 1 Mev obviously corresponding to the production of evaporation neutrons. The rest of the spectrum can be accounted for by considering the production of neutrons by high-energy events and the subsequent slowing down of the neutrons and eventual capture by nitro-

gen. This neutron spectrum is being used to calculate the neutron albedo from the atmosphere of the earth.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

BA10. Measurements with a Large Extensive Air Shower Detector. PAUL H. BARRETT, *University of California, Santa Barbara.*—Large cosmic-ray extensive air showers (10^6 to 10^8 particles) have been detected with an array of Čerenkov counters covering approximately 0.4 km². The analysis of data collected during 20 months of operation will be presented. Because of their importance in relation to theories of the origin of cosmic rays, the possible diurnal variation of the primary cosmic rays causing these showers will be discussed.

BA11. Method for Determining the Mean Free Path of the *N* Component of Cosmic Rays.* M. B. HOMMEL, *New York University.*—Using IGY cosmic-ray neutron monitor data from Fairbanks, Alaska ($\lambda = 64°$N), a method has been developed for calculating the mean free path for absorption of the nucleonic component. The pressure coefficient k is calculated from the formula $I = I_0 e^{kbP}$. Results are in agreement with those taken at lower latitudes.[1] The effect of cosmic-ray intensity variations has been minimized by taking periods of large pressure changes (>10 mm Hg), in short periods of time (<two days). The calculations were done using a least-squares method on an IBM 650 computer.

* Supported in part by the U. S. National Committee for the IGY.
[1] J. A. Simpson, Phys. Rev. **90**, 934 (1953).

BA12. On the Energy Determination of High-Energy Nuclear Interactions of α Particles and Heavy Nuclei from the Angular Distribution of Shower Particles.* E. LOHRMANN, P. L. JAIN,† AND MARTIN W. TEUCHER, *University of Chicago.*—The angular distribution of 77 interactions of α particles and of 26 heavy nuclei in nuclear emulsion have been measured. The primary energy of these particles was determined by the opening angle of fragments and by multiple scattering measurements. These values for the primary energy are compared with those found from the angular distribution of the shower particles. The average particle energies were 10 Bev/n, 24 Bev/n, and 40 Bev/n. The energy values as determined from the angular distribution show large fluctuations around the true primary energy. For interactions which are relatively unaffected by secondary collisions in the same nucleus, the primary energy is on the average overestimated by a factor of 2 if one determines it from the angular distribution only. This discrepancy can be explained by taking properly into account the energy and angular distribution of the mesons in the center-of-mass system.

* Supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission, and by the National Science Foundation.
† On leave from the University of Buffalo, Buffalo, New York.

BA13. Nuclear Interaction of About 10^{15} ev in Nuclear Emulsion.* MARCEL SCHEIN, D. M. HASKIN, E. LOHRMANN, AND MARTIN W. TEUCHER, *University of Chicago.*—In a stack of nuclear emulsion consisting of 200 sheets 30×60 cm, 600 μ thick, flown for 13 hr above 110 000 feet from Brownwood, Texas, a nuclear event of type $6+16_p$ was located. The shower could be followed 22 cm through the stack. Three secondary interactions were found by this method. The energy of the primary collision produced by a proton can be estimated from the angular distribution of the charged mesons and from the energy dissipated in the electron-photon cascade originating from the primary interaction. It is found to be close to 10^{15} ev. Therefore, this collision seems to represent the highest energy event found in nuclear emulsion up to this time.

* Supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission, and by the National Science Foundation.

THURSDAY MORNING AT 10:00

WILLARD, South Ballroom

(R. P. HUDSON presiding)

Cryogenics, I, Mostly Superconductivity

C1. Electromagnetic Penetration Depth in Superconducting Aluminum. M. P. GARFUNKEL, *Westinghouse Research Laboratory and The University of Pittsburgh,* AND MANFRED A. BIONDI, *Westinghouse Research Laboratory.*—In a recent publication[1] the frequency dependence of $r \equiv R/R_n$ (the ratio of the electromagnetic surface resistance in the normal and superconducting states, respectively) was reported for superconducting aluminum in the temperature range 0.38 to 1.2°K. From the measured values of r, and the frequency variation of R_n (obtained from the theory of the anomalous skin effect), it has been possible to find the superconducting surface reactance X through the Kronig-Kramers transform, the integral relation between the real and imaginary parts of the surface impedance. The surface impedance has been used to define an effective penetration depth. The frequency variation of the penetration depth shows a marked rise at photon energies near the superconducting energy gap. At low frequencies the penetration depth approaches the superconducting penetration depth λ. At $T = 0$, we obtain the value $\lambda(0) = 5.1 \times 10^{-6}$ cm in good agreement with the value of 4.92×10^{-6} cm obtained from the more direct measurements of Faber and Pippard.[2]

[1] M. A. Biondi and M. P. Garfunkel, Phys. Rev. Letters **2**, 143 (1959).
[2] T. E. Faber and A. B. Pippard, Proc. Roy. Soc. (London) **A231**, 336 (1955).

C2. Anisotropy of the Superconducting Penetration Depth in Tin. A. L. SCHAWLOW AND G. E. DEVLIN, *Bell Telephone Laboratories.*—The temperature dependence of superconducting penetration depth has been measured in tin single crystal plates. A low measuring frequency (100 kc) avoids microwave complications. It is found that the variation with crystal orientation is nontensorial, in agreement with Pippard's microwave experiments. Thus we confirm in an especially simple way, the nonlocal relation between current and magnetic field in a superconductor. The magnitude of the penetration depth depends on crystal orientation in the same manner as does the normal skin depth at microwave frequencies. However, the amount of the penetration depth variation is about 45%, which is much less than the 60% observed in skin depth. The difference probably arises from the fact that the order parameter ξ, which takes the place of the mean free path in the normal metal, is not very much larger than the penetration depth.

C3. Effects of Disolved Nitrogen on the Superconducting Characteristics of Tantalum. W. B. ITTNER III AND D. P. SERAPHIM, *I.B.M. Research Laboratory, Poughkeepsie.*—The adding of a metallic impurity to a monatomic superconductor

is a standard technique employed in experiments where it is desirable to vary systematically some of the material properties of the specimen, e.g., the mean free path or the penetration depth. While it has long been surmised that the addition of a gaseous impurity would produce comparable effects, there has, to our knowledge, been no systematic work carried out to verify this assumption or to measure the magnitude of the effects produced. We give here a preliminary report on some recent work in which the concentration of nitrogen in tantalum has been varied systematically. One effect of the nitrogen contamination is striking. Very small amounts of gas allow, by a mechanism as yet unknown, for the formation of a "substructure" which permits superconducting inclusions to exist at fields considerably higher than the so-called critical field associated with flux exclusion in the bulk of the sample. The general behavior of the contaminated specimens is basically the same as that observed in inhomogeneous alloys containing relatively large metallic impurity concentrations. Work is currently in progress to illuminate the basic mechanisms involved in the formation of a substructure in tantalum, and some recent results are discussed.

C4. Magnetic Size Effects in Zone-Refined Tin Wires at Liquid Helium Temperatures. JULIUS BABISKIN AND P. G. SIEBENMANN, *U. S. Naval Research Laboratory.*—The bulk and the surface magnetoresistive effects of 99.9999% zone-refined tin wires have been studied in longitudinal magnetic fields (H_L) up to ~70 000 gauss and in transverse magnetic fields (H_T) up to ~13 000 gauss. The tin wires were drawn into Pyrex capillaries with diameters of ~250 μ and 500 μ and exhibited a strong magnetoresistive anisotropy which indicates that they were single crystals. The resistance ratios at $H=0$ between 300 and 4.2°K ($R_{300°K}/R_{4.2°K}$) exhibited normal size effects[1] since $R_{300°K}/R_{4.2°K}$ was ~28 000 for the 250-μ wire and ~15 000 for the 500-μ wire, which indicates that $R_{300°K}/R_{4.2°K}$ for the bulk tin was ~10^5 and the bulk mean free path was ~1000 μ. In H_L where the bulk magnetoresistive effect was small, systematic magnetic size effects[2] were observed which were more pronounced and persisted to higher magnetic fields for the smaller specimen. No clear-cut evidence for the type of magneto-oscillatory size effect[3] observed in sodium was observed. In H_T, the bulk magnetoresistive effect was quite large and the magnetic size effects were not distinguishable.

[1] J. E. Kunzler and C. A. Renton, Phys. Rev. **108**, 1397 (1957).
[2] D. K. C. MacDonald, Nature **163**, 637 (1949).
[3] J. Babiskin and P. G. Siebenmann, Phys. Rev. **107**, 1249 (1957).

C5. Isothermal Current-Induced Transitions in Superconducting Tin Films. V. L. NEWHOUSE AND J. W. BREMER, *General Electric, Schenectady.*—The variation of resistance with current has been measured in 0.3- to 0.5-μ films in the region just below the critical temperature. It is known that the transition in such films is complicated by the spontaneous growth of resistive regions due to Joule heating.[1] It has been possible to produce isothermal transitions in which Joule heating plays no part, by applying the current in short pulses to films deposited on high thermal conductivity substrates. The transition measured in this way is due to electromagnetic effects only. It is found to be very broad, to have no discontinuities, and to be independent of film resistivity over the range measured. This is in contrast to the "dc" transition which exhibits discontinuities and hysteresis and is strongly dependent on film resistivity. The critical current I is proportional to film width over a wide range. It is well represented by the expression[2] $IH_c=\text{const}\ H_B^2$ where H_c and H_B are the critical fields of the film and of bulk tin, respectively.

[1] J. W. Bremer and V. L. Newhouse, Phys. Rev. Letters **1**, 282 (1958).
[2] V. L. Ginzburg, Doklady Acad. Nauk S.S.S.R. **118**, 464 (1958).

C6. Thermal Conductivity in the Intermediate State of Tin Alloys. C. A. SHIFFMAN, *The Clarendon Laboratory, Oxford.**—The thermal conductivity of several tin-rich Sn-In alloys has been measured during the destruction of superconductivity by a magnetic field. For the purer specimens thermal resistivity maxima were observed and their magnitudes and temperature dependence were measured. The additional resistivity w_a, which is deduced from the maxima, does not have a simple power dependence on t, and the dependence varies with impurity. Hulm's model[1] for electron scattering by laminar boundaries has been corrected to allow extension to $t \lesssim 1$, and the revised formula has been applied to these results by plotting w_a *vs* $(t^{-4}-1)$. These graphs are linear at high values of t, indicating that electronic conduction dominates there, but show large positive deviations at lower t, where the lattice contribution is expected to become important. The slopes of the linear portions give the size of the laminae of the intermediate state. These are compared with the experimental phonon mean free paths. The comparison is consistent with the results and with the models for phonon scattering by laminar boundaries. The slopes of the linear regions also allow qualitative observations of Δ, the surface energy parameter, as a function of impurity concentration.

* Now at the National Bureau of Standards, Washington, D. C.
[1] J. K. Hulm, Phys. Rev. **90**, 1116 (1953).

C7. Consistency of the Superconductivity Energy Gap. R. E. PRANGE, *University of Pennsylvania.*—The system of fermions with weak attractive two-body forces is considered. The consistency of an energy gap solution of the Green's function equations[1] for this system is examined under the assumption that the effective interaction of particles in the medium is given by an instantaneous two-body potential and that the interaction of particles with holes may be neglected. These are the weakest assumptions possible which lead to a mathematically tractable theory and are considerably more general than those of the Brueckner[2] theory, for example. It is found that the existence of a gap solution to the equations describing the system is critically dependent on the approximation made in solving the equations. A comparison is made with the method of Bardeen *et al.*[3]

[1] A. Klein and R. E. Prange, Phys. Rev. **112**, 994, 1008 (1958).
[2] K. A. Brueckner and J. L. Gammel, Phys. Rev. **109**, 1023 (1958).
[3] Bardeen, Cooper, and Schrieffer, Phys. Rev. **108**, 1175 (1957).

C8. Solution of the Bardeen-Cooper-Schrieffer Equation in the Strong-Coupling Limit.* DAVID J. THOULESS, *University of California, Berkeley.*—We consider a system of fermions which interact only with particles of opposite spin and momentum. We suppose that the matrix element of the interaction is constant in a certain region and vanishes outside it; if any of the pair states in the region of the interaction are singly occupied, they remain so, and such states can be excluded from the region in what follows. Then, if we neglect the kinetic energy, the Hamiltonian is invariant under permutation of pair states in the region, and so its eigenfunctions give rise to well-known irreducible representations of the symmetry group, and a complete set of eigenfunctions can be found. The solutions are exact for a finite system and give results in quantitative agreement with those obtained by Bardeen *et al.*[1] in the strong-coupling limit. The ground state is nondegenerate and is separated from the lowest excited states by an energy independent of the extent of the system. The energy levels are bounded above, and there is a phase transition due to the complete excitation of the system at a temperature $T_c=2\epsilon_0/2k$, where $2\epsilon_0$ is the energy gap at zero temperature.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Bardeen, Cooper, and Schrieffer, Phys. Rev. **108**, 1175 (1957).

C9. Derivation of the Meissner Effect from the Energy Gap.* RICHARD A. FERRELL, *University of Maryland.*—Following Klein[1] and Bardeen[2] one can relate the diamagnetic

behavior of a superconductor to the spectrum of its excited states. But it is not necessary to make conjectures, as Bardeen[2] has done, concerning the matrix elements. Instead, the matrix elements for virtual excitation by a magnetic field can be identified with those for real transitions induced by oscillating fields. Consequently the Meissner effect follows directly from the observable energy gap data, the explanation of which can be regarded as a more basic goal of a microscopic theory. Once such a theory accounts for the gap in the infrared absorption spectrum, it automatically yields to Meissner effect. Questions of gauge invariance, which have received considerable attention lately,[3] are not involved in this derivation of the Meissner effect.

* Investigation supported in part by the Office of Naval Research.
[1] O. Klein, Arkiv. mat., astron. Fys. **31A**, No. 12 (1945).
[2] J. Bardeen, Phys. Rev. **97**, 1724 (1955).
[3] See, for example, G. Wentzel, Phys. Rev. Letters **2**, 33 (1959).

C10. Quantum Theory of Superconductivity and Ferromagnetism. DWAIN B. BOWEN, *North American Aviation.*—The separation of electron-ion variables in the basic Schroedinger equation has been re-examined for application to solids. The distinction that characterizes the present treatment is in retaining the complete Born and Oppenheimer eigenfunction expansion through the stages of calculating the curvature of the ion potential wells so that any approximations that are introduced may be made in a mutually consistent fashion. The most important result of the review is a new term, in the expression for the curvature of the potential wells, that depends on the distribution of electrons in the Brillouin zone. In many cases, the ground state of the system of electrons and ions does not correspond to the ground state of the system of electrons alone, i.e., it is energetically more favorable to move electrons to higher energy states in order to lower the energy of zero-point oscillations of the lattice. To date, the analysis has been applied to superconductivity and ferromagnetism. Specifically, in the tight binding approximation a state of ^2P character leads to superconductivity for a normal spectroscopic doublet, and to ferromagnetism for an inverted doublet. For estimates of the overlap integrals and spin-orbit splitting that might be characteristic of aluminum, a critical field of the order 300 gauss is obtained.

C11. Measurements of Thermoelectricity below 1°K. D. K. C. MACDONALD, W. B. PEARSON, AND I. M. TEMPLETON, *National Research Council, Canada.*—Recent developments[1] in the field of thermoelectricity at very low temperatures, involving measurements on alkali, noble and transition metals will be reviewed. Findings include marked departure from theoretical predictions in magnitude and temperature dependence and surprising variation in magnitude and sign of thermoelectric power with purity.

[1] Cf. MacDonald, Pearson, and Templeton, Phil. Mag. **3**, 657 and 917 (1958); *ibid.* **4** (1959).

C12. Elastic Constants of Solid Argon at 0°K.* R. M. WINTER AND A. A. MARADUDIN, *University of Maryland.*—The vibrational Helmholtz free energy of a crystal at low temperatures separates into the zero-point energy and a temperature-dependent part. If the lattice is strained both of these depend on the strain parameters and hence contribute to the elastic constants. We have calculated the zero-point energy contributions to the elastic constants of solid argon using a Lennard-Jones 6–12 potential with nearest neighbor interactions only. In the quasi-harmonic approximation, the potential energy of the strained lattice is expanded to quadratic terms in the displacements of the atoms from their equilibrium positions, but the force constants now depend on the strain parameters. Using the moment-trace method, we have calculated the even moments of the frequency spectrum (up to μ_{10}) for a strained lattice as functions of the strain parameters, and used inverse Lagrange interpolation[1] to obtain μ_1, which is proportional to the zero-point energy. The corrections to the elastic constants for the static lattice are of the order of 10% in each case, and the Cauchy relation $c_{12}=c_{44}$ is not satisfied at 0°K.

* This work was supported by the U. S. Air Force.
[1] C. Domb and L. Slater, Phil. Mag. **43**, 1083 (1952).

THURSDAY MORNING AT 10:00

National Bureau of Standards, East Building

(B. LAX presiding)

Solid-State Physics, Mostly Nonmetals

CA1. Optical Transmission of Sb, Te, and Other Films in the Vacuum Ultraviolet.* OM P. RUSTGI, W. C. WALKER,† AND G. L. WEISSLER, *University of Southern California.*—In order to observe the optical effects predicted by the Bohm-Pines theory,[1] the transmissivity of Sb and Te films evaporated on a stilbene substrate were measured in the spectral range from 452 to 1050 A. In the case of antimony the transmissivity showed a marked increase beginning near $h\nu=15$ ev and continuing to 27.4 ev. This increase ranged from 0.4% at 15 ev to ~20% at 27.4 ev. Similar results were obtained for Te. In both cases, the onset agrees with the theoretically predicted plasma frequency[1] and with the observed electron energy eigen losses.[2]

* The continued support of the O.O.R. is gratefully acknowledged.
† Present address: University of California, Santa Barbara.
[1] D. Pines, *Solid State Physics* (Academic Press, Inc., New York, 1955), Vol. 1, p. 437.
[2] L. B. Leder and L. Marton, Phys. Rev. **95**, 1345 (1954).

CA2. Absorption of Hypersonic Waves in Quartz. H. BÖMMEL AND K. DRANSFELD, *Bell Telephone Laboratories.*—Akhieser[1] pointed out that an acoustic wave in a crystal leads to a disturbance of the Planck distribution of thermal phonons and subsequently to a dissipation of acoustic energy. It is suggested here that the absorption of longitudinal and possibly transverse waves in quartz at microwave frequencies[2] is caused by the following process: Different branches of the thermal phonon spectrum are undergoing different temperature changes when a compressional acoustic wave is passing through the crystal. This is because Grueneisen's constant is different, for the various branches, as has been measured for a few directions by C. Susse.[3] For example, immediately after compression each branch has, in general, a different temperature, and equilibrium is only approached in a relaxation time determined by Umklapp processes with phonons of other branches. An estimate for the acoustic absorption agrees in magnitude and temperature dependence with our absorption measurements on quartz. The calculations are similar to those for other relaxation processes; see, for example, Kneser.[4]

[1] A. Akhieser, J. Phys. USSR **1**, 277 (1939).
[2] H. Bömmel and K. Dransfeld (submitted to Phys. Rev. Letters).
[3] C. Susse, J. phys. radium **16**, 348 (1955).
[4] H. O. Kneser, Ergeb. exakt. Naturw. **22**, 121 (1949).

CA3. Determination of Fermi Surface Contours in Graphite. D. E. SOULE, *National Carbon Research Laboratories.*—The extremely elongated (11 to 1) Fermi surfaces in graphite have been mapped using the orientation dependence of the de Hass-van Alphen period as observed in the magnetoresistance. Two magnetic field rotation schemes were used: $Z \perp I$, C_0 and $Z \| I$, where Z is the rotation axis, I the current direction ($I \perp C_0$), and C_0 the hexagonal axis. Both systems give identical results directly showing that the energy surfaces of graphite have 2-dimensional isotropy (within 1%) in the basal plane. The ellipsoidal Fermi surface projecting up from the plane was found to have a slight dumbbell-like distortion. Separation of the electron and hole components was accomplished by least-square fitting[1] using an IBM-704 computer. The measurements were extended over essentially all orientations in the range from 4.2 to 1.2°K. The effective mass variation was studied from both the magnetic field H and the temperature dependence of the oscillation amplitude. For $\theta \gtrsim 80°$, where θ is the angle between H and C_0, the amplitude of the oscillations drops to $<0.005\%$ of its original amplitude at $\theta = 0$ because of the large anisotropy. To obtain the required sensitivity, the amplified difference between the magnetoresistance signal and the voltage from an InSb Hall sensor was observed.

[1] J. W. McClure and L. B. Smith, Bull. Am. Phys. Soc. Ser. II, **4**, 168 (1959).

CA4. Oxidation and Regeneration of Clean Germanium Surfaces. S. P. WOLSKY AND E. J. ZDANUK, *Raytheon Manufacturing Company* (introduced by W. F. Leverton).—The thermal restoration of oxygenated argon-ion bombarded germanium surfaces at 600°C has been investigated. A quartz microbalance housed in an ultra-high vacuum system was used. Weight changes of 0.1 μg were detected. The following assumptions were used in analyzing the experimental results. (1) No free oxygen was desorbed by the thermal treatment; (2) the observed weight loss was due solely to the vaporization of GeO. On this basis preliminary indications are that the regeneration process is due primarily to the removal of oxygen as GeO and, to a lesser extent, to the diffusion of oxygen into the bulk material. Experiments are in progress to determine the exact nature of the desorbed species. The kinetics of the oxygen chemisorption on ion-bombarded and regenerated surfaces were also observed.

CA5. Majority Carrier Recombination in Germanium.* G. ASCARELLI AND SANBORN C. BROWN, *MIT.*—We have studied the recombination of electrons and antimony donors in high-purity germanium by microwave techniques. The recombination is bimolecular, taking the form of an exponential when the density of electrons becomes smaller than the density of compensating impurities. The recombination cross section varies as $T^{-2.3}$, which is in agreement with our calculations from a coincident phonon-photon emission ($\sigma = 1.8\ 10^{-11}$ cm^2 at 4.2°K). We have not been able to decide whether the recombination mechanism is the cascade process proposed by Lax[1] or a recombination with a coincident phonon-photon emission. Recombination light has been detected. The impurities can be re-ionized by high-energy phonons produced during breakdown which exhibit a slower decay rate. The decay of the phonon component can be separated from the electron component by (1) its dependence upon the electric field applied during breakdown, (2) the dependence of the time constant upon sample size, (3) the independence of the time constant on temperature, and (4) the results of a separate experiment that demonstrates the existence of a heat pulse originating from the hot electrons, which will be described.

* This work was supported in part by the U. S. Army (Signal Corps), the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), and the U. S. Navy (Office of Naval Research).

[1] M. Lax, International Conference on Semiconductors, University of Rochester (August 18–22, 1958).

CA6. Possible Role of Microscopic Inhomogeneities in Producing the Anomalous Behavior of *p*-Type Indium Arsenide. JACK R. DIXON, *U. S. Naval Ordnance Laboratory.*—Anomalous electrical properties of *p*-type InAs have been observed by several workers.[1,2] However, the anomalies can be removed by appropriate heat treatment.[3] The electrical, optical, and thermal properties of anomalous material appear to be mutually contradictory when interpreted in terms of the usual models applied to homogeneous semiconductors. However, they become consistent with one another when analyzed in terms of a model involving inhomogeneities arising from the inclusion of microscopic *n*-type regions in *p*-type material. Such small *n*-type regions could arise from the aggregation of *n*-type impurities about dislocations. It will be shown that microscopic inhomogeneities of this type can contribute very significantly to Hall voltages measured on *p*-type semiconductors having a large electron to hole mobility ratio, which is the case for InAs. Recent work by Rupprecht has shown that the anomalies can be removed by etching.[3] This suggests that the small *n*-type regions postulated above may be in the form of a surface layer.

[1] O. G. Folberth and H. Weiss, Z. Naturforsch. **11a**, 510 (1956); R. H. Harada and A. J. Strauss, Chicago Midway Laboratories Contract Report, CML-TN-P108-14 (July 31, 1958).
[2] J. R. Dixon, Bull. Am. Phys. Soc. Ser. II, **3**, 120 (1958); J. R. Dixon, J. Appl. Phys. (to be published).
[3] H. Rupprecht, Z. Naturforsch. **13a**, 1094 (1958).

CA7. Some Electrical and Optical Properties of *P*-Type Zinc Sulfide. R. M. POTTER AND M. AVEN, *General Electric Company, Cleveland.*—Previous measurements of infrared stimulation and quenching,[1] excitation of infrared fluorescence[2] and infrared photoconductivity[3] on copper-activated zinc sulfide have revealed bands peaking at approximately 2.1 and 0.95 ev. In an experiment where uncoactivated substitutional copper was introduced into zinc sulfide by the radioactive decay of Zn-65, it was established[4] that these bands were due to hole transitions between the valence band and the acceptor levels introduced by copper. In the present work it was found possible to prepare by chemical methods copper-activated zinc sulfide powders and single crystals exhibiting infrared fluorescence of strength comparable to that of the radioactivated sample, which contained about 10^{18} cm^{-3} uncompensated copper centers. These crystals were excepted to exhibit *P*-type conductivity with an activation energy corresponding to the tail of the first absorption band or about 1.2 ev. Conductance *versus* temperature measurements on the single crystals gave an activation energy of 1.22 ev, in good agreement with the optically determined value. Thermoelectric emf measurements have confirmed that the sign of the charge carriers is positive.

[1] N. F. Melamed, J. Electrochem. Soc. **97**, 33 (1950).
[2] P. F. Browne, J. Electronics **2**, 1 (1956–1957).
[3] F. G. Ullman and J. J. Dropkin, Enlarged Abstr. of the Electrochemical Societies Meeting, New York (Spring 1958), p. 66.
[4] M. Aven and R. M. Potter, see reference 3, p. 48.

CA8. Microwave Magnetic Rotation in Semiconductors.* C. J. LIN, *University of Pennsylvania* (introduced by C. W. Ufford).—Microwave Faraday rotation and cyclotron resonance experiments can, in many ways, be considered to be complementary. Both measurements are practicable and independently meaningful only under specific conditions. The experiment which will be described is a combination of Faraday rotation, phase shift, and absorption measurements, from which one can determine all the information required to obtain the propagation constant as a function of the magnetic field and temperature. From a theoretical analysis based strictly upon the Boltzmann transport equation, the measured quantities can be correlated with a set of properly defined conductivity functions. From these functions, one can deduce the Hall coefficient, magnetroesistance, and the values of the effective masses, at least for the case of simple ellipsoidal

energy surfaces as a function of magnetic field and temperature. While the samples actually studied were single crystals of lightly doped Ge and Si, this experimental scheme can, in principle, be used on many other crystals. The *X*-band microwave setup used was essentially a Jamin interferometer with a rotation measuring device. The sample chamber was a section of cylindrical wave guide, thus making a straightforward theoretical interpretation possible.

* This work is supported by the U. S. Air Force under a contract from the Wright Air Development Center.

CA9. Field-Induced Switching Cycle in Stibnite.* D. M. MATTOX AND LEE GILDART, *University of Kentucky.*—A stibnite crystal containing about 2% antimony can be made to switch repeatedly between the values of 10^4 and 10^{10} ohms purely by electrical means. Breakdown requires a voltage pulse of about a microsecond duration at fields of the order of 10^3 v/cm as has been described,[1] the crystal then having a resistance of about 10^4 ohms. Restoration of the original resistance, 10^{10} ohms, can be accomplished by means of (a) rf voltage pulses and (b) low-frequency voltage pulses, at fields of about 10^3 v/cm. The time required for restoration is about a millisecond. Breakdown and restoration thus constitute a complete, electrically induced switching cycle, which is indefinitely repeatible. Other Group V–Group VI compound semiconductors have been examined, but only stibnite containing excess antimony has been found to possess this behavior.

* This research was supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.

[1] J. R. Davis and L. Gildart, Bull. Am. Phys. Soc. Ser. II, **3**, 218 (1958).

CA10. Electrical Resistivity and Hall Coefficient of a TiB_2 Single Crystal. WENDELL S. WILLIAMS AND R. T. DOLLOFF, *National Carbon Research Laboratories.*—Electrical measurements have been made on a 1- ×3- ×10-mm single crystal of TiB_2 at room temperature and liquid nitrogen temperature. It is believed that these are the first reported measurements on a single crystal of this refractory compound. The resistivity is metallic: 6.9±0.3 μohm-cm at 300°K and 1.20±0.05 μohm-cm at 77°K. The measured Hall coefficient is $-(18.0\pm0.7)\times10^{-4}$ cm³/coul. at 300°K and $-(19.3\pm0.7)\times10^{-4}$ cm³/coul. at 77°K. These values can be compared with those of Juretschke and Steinitz for hot-pressed TiB_2 powders: 8.7 μohm-cm and -24×10^{-4} cm³/coul. at 300°K.[1]

[1] H. J. Juretschke and R. Steinitz, J. Phys. Chem. Solids **4**, 118 (1958).

CA11. Mechanical Stimulation of CdS Edge Emission. D. M. WARSCHAUER AND D. C. REYNOLDS, *Aeronautical Research Laboratory.*—Mechanical stimulation of edge emission in cadmium sulfide has been reported earlier.[1] The optical threshold for activation has been found to be 6900 A, while thermal activation can be accomplished by warming above −80°C. Controlled mechanical stimulation is difficult to achieve, but a qualitative difference between the two types of activation has been observed, the thermally stored energy release being much easier to stimulate. Optical activation produces persistent conductivity at N_2 temperature before energy release which is absent after thermal activation. Although the mechanically stimulated emission occurs along the *C* axis, the radiation itself does not appear to be polarized. In CdS:Ag, the uv-excited red emission is polarized $\perp$ *C* axis, while transmitted light is polarized parallel to the *C* axis. Our model contains two sets of mechanically stimulated hole traps, a set of electron traps, and a silver level where applicable. The upper hole traps are approximately at midgap at N_2 temperature, and get closer to the conduction band as the temperature is raised.

[1] Blakewood, Warschauer, and Reynolds, Bull. Am. Phys. Soc. Ser. II, **4**, 45 (1959).

CA12. Efficiency and Mechanism of Electroluminescence in ZnS. F. F. MOREHEAD, *General Electric Company, Cleveland.*—A relation between electroluminescence brightness and input power is proposed, based on a steady-state model,[1] similar in concept, but differing in important details from that described by Lehmann.[2] Measurements of power W and brightness B as functions of voltage V, frequency f, and temperature T correlate well on the basis of the model, except at the very highest applied fields. The equations are: $B=B_\infty f[1-\exp(-\mu)]\exp[-2c/(V+V_0)]$; $W=\omega C'' V^2$; $C''=C_0''+C_1''[1-\exp(-\mu)]\exp[-c/(V+V_0)]$; and $\mu=(k_\mu V/f^{0.6})\times\exp(-E_0/kT)$, where E_0 is an effective electron trap depth. An upper limit to the efficiency can be calculated, permitting the exclusion of those mechanisms of high field formation which are too lossy to be consistent with measured efficiencies.

[1] F. F. Morehead, J. Electrochem. Soc. **105**, 461 (1958).
[2] W. Lehmann, J. Opt. Soc. Am. **48**, 647 (1958).

THURSDAY MORNING AT 9:30

Room B in Departmental Auditorium

(A. PAIS presiding)

Theory, I: Weak Interactions

D1. Relativistic Rotator Model for Mesons and Hyperons. E. J. STERNGLASS, *Westinghouse Research Laboratories.*—Following suggestions that mesons and hyperons may represent excited states of electrons and nucleons,[1] recently supported by striking mass-regularities,[2] the experimental masses, parities, decay energies, and scattering resonances were found to fit the rotator-like states, $W_{j,j_0}=Mc^2=(1/2)(1/\alpha)m_0c^2\times[j(j+1)+j_0^2]+(1/2)(1/\alpha)m_0c^2+n_bM_pc^2$, where m_0 and M_p are the electron and proton masses; $\alpha=e^2/\hbar c$; $j=0,1,2,3\ldots$; $j_0=s-1$, where $s=0$ for mesons, +1 for leptons, −1 for hyperons; n_b is the baryonic number ($n_b=1$ for $s=-1$; 0 for $s=0$, +1). Decays obey the selection rules $\Delta j=0$, ±1, (±2); $\Delta s=0$, ±1 and $\Delta s+\Delta j=0$, ±1, (±2). The observed parities are reproduced by $P=(-1)^{(j+s+n_b)}$. The rule $\Delta s=0$, ±1 excludes "leptonic" hyperon decay. W_{j,j_0} may be interpreted as rotational levels of a relativistic electron with ground-state mass $(1/\alpha)m_0$, moving in orbits $r\simeq(1/2)(e^2/m_0c^2)$ and quantized in units of $(\hbar/2)$, suggested by an extension of Sommerfeld's theory to $v\simeq c$.[3] Since collision processes require $\Delta L=n\hbar$, Δj must equal $2n$, where $(n\geq1)$, thus prohibiting single production of μ and Ψ particles as observed.

[1] M. Sugawara, Progr. Theoret. Phys. (Japan) **7**, 599 (1952).
[2] H. Fröhlich, Nuclear Phys. **7**, 148 (1958); Y. Nambu, Progr. Theoret. Phys. **7**, 595 (1952).
[3] E. J. Sternglass (submitted to Phys. Rev.).

D2. Møller Scattering of Electrons with an Electric Dipole Moment. KIRK W. MCVOY, *Brandeis University.*—Feinberg and Salpeter[1] have recently pointed out that the known properties of systems containing bound electrons establish an upper limit of $\lambda<4\times10^{-3}$ for a possible static electric dipole moment of the electron, where the dipole moment is $\lambda e\hbar/mc$. Margolis *et al.*[2] have suggested that electron-nucleus scattering might be used to establish a smaller limit on λ. Still another, rather sensitive, possibility is electron-electron scattering at very high energies, such as that being contemplated at Stanford. The center-of-mass cross section in the extreme relativistic limit ($m/E=0$) is $d\phi/d\Omega=e^4(E^6\sin^6\theta)^{-1}|(16-8\sin^2\theta+\sin^4\theta)+\frac{1}{2}(\lambda E/m)^2(4-\sin^2\theta)\sin^2\theta+(1/16)(\lambda E/m)^4(28-\sin^2\theta)\sin^4\theta|$, E and θ being the c.m. energy and scattering angle. A 20% effect on the angular distribution is readily observable at $E=m/\lambda$; at $E=125$ Mev, the sensitivity equals that of the Lamb shift.

[1] G. Feinberg and E. E. Salpeter, Phys. Rev. **112**, 1637, 1642 (1958).
[2] Margolis, Rosendorff, and Sirlin (to be published).

D3. Effect of Collective Interactions in Nuclear Matter on the Inelastic Scattering of High-Energy Electrons.* ARNOLD J. GLICK AND RICHARD A. FERRELL, *University of Maryland.*—The scattering of a charged particle by an electron gas can be described by means of a dynamic dielectric constant for the electron gas.[1] Such a description contains both the individual particle and collective response of the electrons to the incident charge. An analogous frequency and wave-number dependent dielectric constant has been derived for nuclear matter from a nonsingular, short range, spin and isotopic spin dependent interaction between nucleons. The differential cross section for the inelastic scattering of high-energy electrons can be calculated along lines similar to those followed for the electron gas. The deviation of the dielectric constant from unity describes the modification of the interaction between the incident electron and the individual nucleons which results from intermediate nucleon-hole pairs. Of particular interest is the behavior of the cross section for those energies where $T=1$ waves are expected, since such waves correspond to the giant electric dipole resonances in finite nuclei.

* Investigation supported in part by the U. S. Atomic Energy Commission.
[1] J. Hubbard, Proc. Roy. Soc. (London) **A68**, 976 (1955).

D4. Excitation of Nuclear Giant Dipole Resonance by Electron Scattering.* MANOJ K. PAL, STAVROS FALLIEROS, AND RICHARD A. FERRELL, *University of Maryland.*—With the method of Hill, Wheeler, and Griffin[1] a deformed state of a closed shell nucleus can be generated by the prescription that protons and neutrons are displaced by $\pm a$ along a preassigned axis. Following Ferrell and Visscher[2] we differentiate the deformed wave function with respect to a to obtain the first excited state of the electric dipole vibration. For O^{16}, this state consists of excitation of $1p$-nucleons to the $2s$ and $1d$ shells and is of the type investigated by Elliott and Flowers.[3] The form factor for the excitation of this state by inelastic electron scattering is found to be simply proportional to the product of the elastic form factor times the momentum transfer $\hbar q$, and has a maximum at roughly $q=0.6\times10^{13}$ cm^{-1} for O^{16} corresponding to relatively small angles of scattering.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] J. J. Griffin and J. A. Wheeler, Phys. Rev. **108**, 311 (1957).
[2] R. A. Ferrell and W. M. Visscher, Phys. Rev. **102**, 450 (1956).
[3] J. P. Elliott and B. H. Flowers, Proc. Roy. Soc. (London) **A242**, 57 (1957).

D5. Matrix Elements of First-Forbidden Transitions and K/β^+ Ratios.* DON S. HARMER, *Brookhaven National Laboratory and Georgia Institute of Technology,* AND M. L. PERLMAN, *Brookhaven National Laboratory.*—The relative probabilities of K-electron capture and of positron emission which have been observed in the $(2-)\beta(2+)\gamma(0+)$ transitions of As^{74}, Rb^{84}, and I^{126} are all greater than those characteristic of allowed transitions. Calculation of the K/β^+ ratio characteristic of each of the several matrix elements contributing to first-forbidden transitions shows that only $|\int\sigma\times r|^2$ and $\Sigma|B_{ij}|^2$ can give rise to comparatively large ratios. The fact that matrix elements other than these two should be of magnitude comparable to $|\int\sigma\times r|^2$ makes it seem probable that the large K/β^+ ratios observed are attributable to contributions of $\Sigma|B_{ij}|^2$, which alone produces ratios several times the allowed values. This argument is supported by shell-structure considerations. The magnitudes of $\Sigma|B_{ij}|^2$ in these $2-\rightarrow2+$ transitions have been calculated from an analysis of the observed K/β^+ ratios; the value for each nuclide is not greatly different from the value of $\Sigma|B_{ij}|^2$ for the unique $2-\rightarrow0+$ ground-state transition. Furthermore, values of $\Sigma|B_{ij}|^2$ for all these transitions, $2-\rightarrow0+$ and $2-\rightarrow2+$, are in good agreement with values calculated from shell-model wave functions. The significance of the relatively large values of $\Sigma|B_{ij}|^2$ in the $2-\rightarrow2+$ transitions will be discussed in relation to the descriptions of the first-excited states of the even-even daughter nuclides.

* Research performed in part under the auspices of the U. S. Atomic Energy Commission.

D6. Electric Quadrupole Interaction in Beta Decay. J. M. PEARSON, *McMaster University.*—In the beta decay of strongly deformed nuclei the electrostatic field in which the decay electron moves by no means possesses the spherical symmetry that it has been customary to assume in beta-decay theory. The angular momentum of the electron will not be conserved, and different, closely lying, rotational states of the daughter nucleus will be coupled together. Such a coupling appears to provide a natural explanation for observed anomalies in the branching of first-forbidden transitions to different rotational states of the daughter nucleus: the branching ratios in the decays of Lu^{176}, Ta^{180}, and Np^{236} depart appreciably from the value given by Alaga *et al.*[1] In the present work an exact treatment of the quadrupole interaction has been made, from which the Dirac electron wave functions are coupled together in sets of up to twelve first-order differential equations. It is found that the only significant coupling of nuclear states is associated with electron states belonging to higher degrees of forbiddeness, from which the quadrupole coupling of the kind considered here will not generally be important and the explanation for the anomalous behavior of the branching must lie elsewhere.

[1] Alga *et al.*, Danske Mat.-fys. Medd. (1955).

D7. Double Beta Decay with Incompletely Polarized Majorana Neutrinos.* R. C. WHITTEN AND E. GREULING, *Duke University.*—Double beta decay without the emission of neutrinos is investigated under the assumption that leptons are not conserved. If either the neutrino mass is not zero or its helicity deviates from 100% in the universal V-A interaction[1] containing the Majorana neutrino field, the intermediate state neutrino is not completely polarized and may be reabsorbed. Plausibility arguments are given for the latter possibility. Mean lives for the neutrinoless mode are computed for several nuclei using Coulomb electron spinors. The Coulomb effect greatly influences the transition rates, especially for nuclei of high Z and low kinetic energy release. The results are compared with the corresponding mean lives for two neutrino double beta decay and the implications of the occurence of the neutrinoless mode are discussed.

* This work was supported by the National Science Foundation.
[1] R. P. Feynman and M. Gell-Mann, Phys. Rev. **109**, 193 (1958).

D8. Conservation of Current in Weak Interaction. SUSUMU OKUBO. *University of Rochester.*—It is proved that we cannot construct a conserved strangeness-violating current, which has a form consisting of a baryon current plus a meson term. This proof is independent of explicit form of the meson term, if we assume nonderivative couplings for the strong interactions.

For more general cases, we cannot give such a definite statement, but a similar argument seems to suggest that it is rather unlikely to have a conserved current. However, if we neglect the mass differences between the nucleons and the hyperons, then this is possible to do, and some examples of this type of approximately conserved strangeness-violating current are given. Furthermore, the relation between the conservation of a current and the lack of renormalization is investigated. Under some conditions, we can prove that the conservation of a current means no need for renormalization, which is a kind of a generalization of the Ward's identity. In this proof, the explicit form for the meson term is not important at all, and so it is applicable also for a conserved current other than the usual Feynman—Gell-Mann current, if any.

D9. Nuclear Shell Effects in Mu-meson Capture. G. H. BURKHARDT, *Columbia University*, AND C. A. CAINE, *Clarendon Laboratory, Oxford* (introduced by R. Serber).—The total capture rates for negative muons in N^{14}, O^{16}, and F^{19} have been calculated using the closure approximation to evaluate the sum over the many possible final states of the daughter nucleus. The initial nuclear ground state is represented by a refined shell-model state, including configurational mixing in the unfilled shell. The results cast some light on the nature of the weak interaction and a comparison with other decay processes is made. The validity of the approximations is examined in some detail.

D10. Hyperfine Splitting Effects in the Capture of Polarized μ^- Mesons. H. ÜBERALL, *Carnegie Institute of Technology.*—Mu-mesic atoms with spin exist in two incoherent hyperfine states,[1] which decay with two different lifetimes. If the muons still possess a polarization upon arrival in the K shell, the neutrons emitted in the capture process are predicted to show an asymmetry which differs from the one expected from spinless nuclei, even after averaging over the hyperfine states. This originates from a polarization of the capturing proton induced when the hyperfine interaction flips the muon spin. The effect has been ignored in earlier papers on neutron asymmetries,[2] and is investigated by us for muon capture in hydrogen, in deuterium, and in complex nuclei treated by the Schmidt model. We find a Fermi-Gamow-Teller interference which distinguishes between $V+A$ and $V-A$ coupling. We also calculate gyromagnetic ratios in the mesic atom ground states.

[1] Bernstein, Lee, Yang, and Primakoff, Phys. Rev. **111**, 313 (1958).
[2] Shapiro, Dolinsky, and Blokhintsev, Nuclear Phys. **4**, 273 (1957); Huang, Yang, and Lee, Phys. Rev. **108**, 1340 (1957); L. Wolfenstein, Nuovo cimento **7**, 706 (1958); **8**, 882 (1958); H. Überall and L. Wolfenstein, Nuovo cimento **10**, 136 (1958).

D11. Relativistic Corrections to Formulas for Allowed Beta Decay. M. MORITA, *Columbia University.*—Several formulas for the characteristics of allowed beta decay have been published in which the relativistic corrections (the corrections due to the momentum type matrix elements) are taken into account. These corrections become important when the electron energy is very large.[1] The corrections can be derived for all beta-decay phenomena from the following rule. The formulas with these corrections for the allowed transitions can be obtained from those for the first-forbidden transitions of the relevant phenomena when the matrix elements are replaced as follows: $\mathfrak{M}(\gamma_5) \to \mathfrak{M}(1)$, $\mathfrak{M}(\boldsymbol{\sigma}\cdot\mathbf{r}) \to \mathfrak{M}(\boldsymbol{\alpha}\cdot\mathbf{r})$, $\mathfrak{M}(\boldsymbol{\alpha}) \to \mathfrak{M}(\boldsymbol{\sigma})$, $\mathfrak{M}(\boldsymbol{\sigma}\times\mathbf{r}) \to \mathfrak{M}(\boldsymbol{\alpha}\times\mathbf{r})$, $\mathfrak{M}(\mathbf{r}) \to \mathfrak{M}(\gamma_5\mathbf{r})$, $\mathfrak{M}(B_{ij}) \to \mathfrak{M}(A_{ij})$, $C_V \rightleftarrows C_A$, $C_V' \rightleftarrows C_A'$. This rule can be easily proved because (a) the interaction Hamiltonian of the beta decay is invariant under the transformation, $\psi_n \to \gamma_5\psi_n$, $\psi_\nu \to -\gamma_5\psi_\nu$, $C_V \rightleftarrows C_A$, $C_V' \rightleftarrows C_A'$, and (b) ψ_ν and $-\gamma_5\psi_\nu$ satisfy the same equation of motion with $m_\nu=0$. A generalization of the present work to the higher forbidden transitions and to the coordinate type matrix elements should also be possible.

[1] M. Gell-Mann, Phys. Rev. **111**, 362 (1958); J. Bernstein and R. R. Lewis, Phys. Rev. **112**, 232 (1958).

D12. Induced Pseudoscalar Interaction in $\Lambda \to p+\mu+\nu$. L. WOLFENSTEIN, *Carnegie Institute of Technology.*—The universal theory of the Fermi interaction predicts too large a rate for the decays $\Lambda \to p+\mu+\nu$ and $\Lambda \to p+e+\nu$. It has been suggested that this may be due to the corrections caused by virtual strong interactions. We consider the simplest of these, the analog of the induced pseudoscalar interaction[1] in mu-meson capture. In the present case this corresponds to $\Lambda \to p+K$, $K \to \mu+\nu$. Because of the larger K-meson mass the effective pseudoscalar interaction is found to be considerably less than C_A (the axial-vector coupling) instead of 8 C_A as for mu-meson capture. If the Fermi interaction is due to an intermediate spin-one boson B, a different effective pseudoscalar interaction C_p' may arise from the form of the B propagator: C_p'/C_A equals approximately $2(m_\Lambda+m_p)m_\mu/B^2$. Since m_B must be greater than the K-meson mass, $C_p'/C_A<1.7$. Both of these pseudoscalar interactions are completely negligible for $\Lambda \to p+e+\nu$, and while the second might have a small measurable effect on $\Lambda \to p+\mu+\nu$ it cannot explain the low decay rate. We note incidentally that a pseudoscalar interaction associated with an intermediate boson could change the value of the induced pseudoscalar coupling in mu-meson capture by as much as 20%.

[1] L. Wolfenstein, Nuovo cimento **8**, 882 (1958); M. L. Goldberger and S. Treiman, Phys. Rev. **111**, 355 (1958).

D13. Six(Seven)-Dimensional Charge Space.[7] D. C. PEASLEE, *Purdue University.*—Assumption of a charge space with six linear (or equivalently seven rotational) coordinates may have some advantages. Formally, the baryon and boson interactions are describable in terms of 6-D Dirac and Kemmer matrices, which provides a correlation between the charge space characters and statistics of these particles. The corresponding 7-D rotational space has 21 rotation operators, of which 9 are immediately related to familiar quantities like isotopic spin. Incorporation of leptons into 6-D charge space provides an excuse for the existence of the μ meson; it also suggests that the lepton-antilepton distinction is less significant than that between baryon and antibaryon. The (μ,e) mass difference must be regarded as "intrinsic": the (Ξ,N) and (K,π) mass differences appear to be largely of the same same character. The 6-D formalism is convenient for writing a universal four-fermion interaction; it is also exhaustive, having 128 parameters.

* Work performed at the Australian National University, Canberra, under 1958 Fulbright Program.

D14. Hyperon Decay Asymmetries, Selection Rules, and the Nature of the Weak Interaction.* BERNARD T. FELD, *MIT.*—Recent observations by Cool, Cork, Cronin, and Wenzel on the pionic decays of the Σ hyperons, which indicate (maximum) parity violation only in the $p\pi^0$ decay mode of the Σ^+, have their simplest interpretation in terms of the $\Delta T=\frac{1}{2}$ selection rule. The difficulty in reconciling the "universal" β-decay interaction, in the form suggested by Marshak and Sudarshan, with these data suggests that its success in accounting for the Λ^0-decay asymmetry may be fortuitous. A phenomenological "spurion" theory, with the constants determined by the Σ decays, encounters some difficulty in fitting the Λ^0-decay properties, although the differences are not excessively far outside of present experimental uncertainties. An approach, first developed by R. A. Sawyer, based on a "global" symmetry for the pion interaction and on violation of this symmetry by the K-meson interaction describes in a relatively natural fashion the observed Σ and Λ decays. Experiments for distinguishing between theories will be discussed. In particular, the global and spurion theories predict opposite directions of longitudinal polarization of the proton (sign of the asymmetry parameter) in the decay $\Sigma^+ \to p+\pi^0$.

* Work supported by joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

THURSDAY MORNING AT 9:00

National Academy of Sciences

(ROBERT JASTROW presiding)

Symposium on Problems in Space Exploration, II

DA1. Capabilities for Space Research. HOMER E. NEWELL, *National Aeronautics and Space Administration.* (30 min.)
DA2. The Moon. G. P. KUIPER, *Yerkes Observatory.* (30 min.)
DA3. Primary and Secondary Objects. H. C. UREY, *University of California, La Jolla.* (30 min.)
DA4. Mars and Venus. G. DE VAUCOULEURS, *Harvard College Observatory.* (30 min.)

Round-Table Discussion

BRUNO ROSSI (*Chairman*); speakers of this session, DINSMORE ALTER, A. G. WILSON, R. B. BALDWIN, W. M. SINTON, ROBERT DIETZ, T. GOLD.

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THURSDAY AFTERNOON AT 2:00

National Academy of Sciences

(H. C. UREY presiding)

Symposium on Problems in Space Exploration, III

E1. Rocket Astronomy. HERBERT FRIEDMAN, *Naval Research Laboratory.* (30 min.)
E2. Astronomy from Satellites and Space Vehicles. LEO GOLDBERG, *The University of Michigan.* (30 min.)
E3. Experimental Research Program in the Space Sciences. J. W. TOWNSEND, *National Aeronautics and Space Administration.* (30 min.)
E4. Outer Atmospheres of the Earth and Planets. ROBERT JASTROW, *National Aeronautics and Space Administration.* (30 min.)

Round-Table Discussion

LYMAN SPITZER, JR. (*Chairman*); speakers of this session, H. F. NEWELL, JOHN HAGEN, SIGMUND FRITZ, A. H. SHAPLEY, R. S. GALLET, D. H. MENZEL.

THURSDAY AFTERNOON AT 2:00

Departmental Auditorium

(E. P. WIGNER presiding)

Symposium on Precise Neutron Cross Sections

EA1. Nuclear Constants and the Present Status of Nuclear Technology. A. M. WEINBERG, *Oak Ridge National Laboratory.* (30 min.)
EA2. Thermal Cross Sections and Parameters of Fissile Nuclei. W. W. HAVENS, JR., *Columbia University.* (30 min.)
EA3. Gamma Rays from Resonant Neutron Capture. L. M. BOLLINGER, *Argonne National Laboratory.* (30 min.)
EA4. Neutron Radiative Capture Cross Sections from 10–150 kev. R. L. MACKLIN, *Oak Ridge National Laboratory.* (30 min.)

THURSDAY AFTERNOON AT 1:45

Willard, Congressional Room

(V. F. WEISSKOPF presiding)

Nuclear Reactions, I, Including Coulomb Excitation and Fission

F1. Coulomb Excitation of Ge^{74} and Se^{77}.* W. R. WISSEMAN AND R. M. WILLIAMSON, *Duke University.*—The 593-kev level in Ge^{74} and the 473-kev level in Se^{77} have been excited by 3.8 and 4.0 Mev protons and deuterons, and the inelastically scattered particles were observed at angles between 130° and 150°. Coulomb excitation was assumed and the reduced nuclear transition probabilities, $B(E2)$, were found by observing the ratio of the inelastic peak to the Rutherford peak. The product particle spectrometer has been described previously.[1] It has been adapted for use with a 2-in.×12-in. photographic plate which can detect an energy interval which is 24% of the central energy. A shutter was used to keep the Rutherford peak from hitting the plate for all but about 20 μQ out of a 2000 μQ run; 4 or 5 separate Rutherford exposures were made throughout each run. The value of $B(E2)=0.36\pm0.02\times(e^2\times10^{-48}\ \text{cm}^4)$ was measured for the Ge^{74} level, and a preliminary value for Se^{77} of 0.4 has been found.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Meier, Fletcher, Wisseman, and Williamson, Rev. Sci. Instr. **29**, 1004 (1958).

F2. Coulomb Excitation of the Second 2+ State in Even-Even Medium Weight Nuclei. F. K. MCGOWAN AND P. H. STELSON, *Oak Ridge National Laboratory.*—The location of the second 2+ state has been established for seven even-even medium weight nuclei by means of Coulomb excitation produced by 7 to 10 Mev α particles. The positions of the second 2+ state are (in kev): Ge^{74}, 1200±10; Ge^{76}, 1127±10; Se^{76}, 1220±8, Se^{78}, 1307±9; Se^{80}, 1455±11; Mo^{100}, 1050±9; and Ru^{98}, 1402±10. The $B(E2)$ for excitation of these states are between 0.4 and 1.9 times the independent particle estimate (taking $R=1.2\times10^{-13}\ A^{1/3}$ cm). Using the branching ratio of cascades to crossovers from radioactive decay measurements, the values of the ratio of the upper cascade $B(E2;\ 2'\rightarrow 2)$ to the lower cascade $B(E2;\ 2\rightarrow 0)$ are 0.7±0.2 and 0.8±0.2 for Se^{76} and Se^{78}, respectively. These values are appreciably smaller than the value of 2.0 predicted by the "near harmonic" model. Corrections for double $E2$ excitation and angular correlation effects from the triple cascade have not been included in these values. The corrections will be discussed; however, it appears rather unlikely that the ratio $B(E2;\ 2'\rightarrow 2)/B(E2;\ 2\rightarrow 0)$ will be larger than 1.0. Taking the known value[1] of $E2/M1=49$, we obtain for Se^{76} the exceedingly small value of 4×10^{-4} for $B(M1;\ 2'\rightarrow 2)$.

[1] T. Lindqvist and I. Marklund, Nuclear Phys. **4**, 189 (1957).

F3. Coulomb Excitation of the First 2+ State in Some Medium-Weight Even-Even Nuclei. P. H. STELSON AND F. K. MCGOWAN, *Oak Ridge National Laboratory.*—Coulomb excitation of the first 2+ state has been measured for the 14 even-even nuclei Ni^{58}, Ni^{60}, Ni^{62}, Zn^{64}, Zn^{66}, Zn^{68}, Zn^{70}, Ge^{72}, Ge^{74}, Ge^{76}, Se^{76}, Se^{78}, Se^{80} and Se^{82}. Coulomb excitation was effected by α particles with energies of 3 to 10 Mev. Over this energy range the thick target yield of Ge^{76} excitation varied by a factor of 20 000. Up to 8-Mev α energy the yield followed that expected for Coulomb excitation. Above 8 Mev there were small but significant deviations. The position of the first 2+ state in Zn^{70} (887±9 kev) was not previously known. Our value for the 2+ state in Se^{82} (670±10) kev is different from that previously reported. The absolute $B(E2)$ values are determined to ±10%. For the 3 nuclei, Ni^{60}, Ge^{72}, and Ge^{74}, the Coulomb excitation γ-ray lifetimes may be compared to those obtained by Metzger who used the resonance fluorescence method. There is good agreement. The enhancements over the single-particle transition estimate (taking $r_0=1.20\times10^{-13}$ cm) vary from a low of 11 for Ni^{58} to a high of 47 for Se^{76}. The previously observed constancy of the mass parameter $B_2/(B_2)_{\text{irrot}}$ is also found for the nuclei reported here.[1]

[1] P. H. Stelson and F. K. McGowan, Phys. Rev. **110**, 489 (1958).

F4. Lifetimes of Excited States of Zn^{67}, Se^{77}, and Mo^{95}.* R. E. HOLLAND AND F. J. LYNCH, *Argonne National Laboratory.*—We have measured the mean lifetimes of excited states produced by Coulomb excitation in Zn^{67}, Se^{77}, and Mo^{95}. Alpha particles of 3.5-Mev energy were used in conjunction with a pulsed-beam technique.[1] The isotope, transition energy, and preliminary value of the mean lifetime are; Zn^{67}, 182 kev, 1.6 mμ sec; Se^{77}, 244 kev, <0.4 mμ sec; Mo^{95}, 204 kev, 1.0 mμ sec. For the mean life of Mo^{95}, Quidort[2] obtained 1.11 ±0.04 mμ sec by delayed coincidence measurements and McGowan and Stelson[3] obtained 1.11 mμ sec by measurement of Coulomb excitation.

* This work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Holland, Lynch, and Hanna, Phys. Rev. **112**, 903 (1958).
[2] J. Quidort, Compt. rend. **246**, 2119 (1958).
[3] F. K. McGowan and P. H. Stelson, Phys. Rev. **109**, 911 (1958).

F5. Angular Correlation Measurements for the B^{11}-$(He^3,d\gamma)C^{12}$ Reaction. E. A. WOLICKI, R. L. JOHNSTON, AND H. D. HOLMGREN, *U. S. Naval Research Laboratory*, AND W. F. HORNYAK AND R. LEVESQUE, *University of Maryland.*—Angular correlations of gamma rays, emitted from the 4.43 Mev level in C^{12}, in coincidence with deuterons, were measured for the $B^{11}(He^3,d\gamma)C^{12}$ reaction at a bombarding energy of 4.5 Mev. The gamma-ray detector was rotated in the plane of the reaction, and angular correlations were obtained for deuteron directions of 17°, 30°, 60°, and 124° with respect to the incident beam direction. The measured anisotropies all lie in the range from 20 to 35%. The 17° position corresponds to a peak in the deuteron angular distribution.[1] Although this angular distribution strongly suggests a direct interaction mechanism in the reaction, the angular correlations are not symmetric about the recoil direction of the residual nucleus. A minimum in the angular correlations obtained for deuteron directions of 17°, 30°, and 60° shows a displacement which corresponds approximately to the change in recoil direction. The correlation obtained for a deuteron direction of 124° does not have a symmetry axis. It cannot be expressed, therefore, as a series expansion in cosine terms alone.

[1] Holmgren, Wolicki, and Johnston, Bull. Am. Phys. Soc. Ser. II, **2**, 181 (1957).

F6. Angular Correlation for the $C^{13}(He^3,\alpha\gamma)C^{12}$ Reaction. H. D. HOLMGREN, E. A. WOLICKI, AND R. L. JOHNSTON, *Nucleonics Division, U. S. Naval Research Laboratory.*—The angular correlations of the gamma rays in coincidence with the α particles from the $C^{13}(He^3,\alpha\gamma)C^{12}$ reaction, corresponding to C^{12} being left in the 4.43-Mev state, have been measured for

α particles emitted at 10°, 40°, 90°, and 128° to the direction of the incident beam at a bombarding energy of 4.5 Mev. The amplitudes of the correlation functions are largest for 10° α particles (5:1 peak to valley ratio) and smallest at 90° (1.7:1). For 10° α particles the correlation function can be expressed in the form $1+A\cos^2\theta+B\cos^4\theta$. The correlation function for α particles emitted at 40° requires at least the inclusion of odd powers of $\cos(\theta-\theta_0)$ in the expansions. The correlation functions for the 90° and 128° α particles appear to have no axis of symmetry and thus cannot be expressed in an expansion of only $\cos^n\theta$. The angular distributions of the α particles emitted from this reaction strongly suggest that this reaction proceeds by a direct process[1]; however, the correlation functions do not appear to shift with the recoil axis. For α particles emitted at 10°, 40°, and 90° the correlation functions appear to remain fixed with respect to the beam axis.

[1] Holmgren, Geer, Johnston, and Wolicki, Phys. Rev. **106**, 102 (1957).

F7. Angular Correlation for the $B^{10}(He^3,p\gamma)C^{12}$ Reaction. R. L. JOHNSTON, H. D. HOLMGREN, AND E. A. WOLICKI, *U. S. Naval Research Laboratory.*—The angular distributions of the 4.43-Mev γ rays from C^{12}, from the He^3 bombardment at 4.5 Mev of B^{10}, in coincidence with the emitted protons leaving C^{12} in its first excited state were measured. The observations were made in the plane of the reaction with the proton fixed succesively at 10°, 45°, 90°, and 124°. The anisotropies in the correlations are about 10% at 10°, 45% at 45° and 90°, and 28% at 124°. There exists no simple symmetry axis such as the beam, recoil, or counter direction. Except possibly for the 10° data, there does not appear to be any symmetry axis in the range of observation.

F8. *E2-M1* Mixing Ratios in $2'\rightarrow 2\rightarrow 0$ Transitions.* V.R. POTNIS,† S. S. MALIK,‡ AND C. E. MANDEVILLE, *Bartol Research Foundation.*—The results of thirteen published angular correlation experiments have been analyzed, and the *E2-M1* mixing ratios of the $2'\rightarrow 2$ transitions have been obtained for thirteen different even-even nuclei. Particular attention has been given to evaluation of the errors in the measured values of the mixing ratios. The available data range from $A=56$ to $A=198$. When $(\delta/E_\gamma)^2$ is plotted against $Z^2A^{4/3}$, three of the experimentally observed points, those for Fe^{56}, Zr^{92}, and Hg^{198}, deviate sharply from a curve calculated from the theoretical considerations of Davydov and Filippov.[1] These cases of disagreement will be discussed.

* This research was supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.
† Permanent address: Gwalior (M.P.) India.
‡ Permanent address: Muzaffar Nagar (U.P.) India.
[1] A. S. Davydov and C. F. Filippov, Nuclear Phys. **8**, 237 (1958).

F9. *E2* Transitions from the Second 2+ Level of Even-Even Nuclei.* D. M. VAN PATTER, *Bartol Research Foundation.*—Current interest regarding the asymmetric rotor theory of Davydov and Filippov[1] has led to an extension of a survey[2] to include all available data concerning *E2* transitions from the second 2+ level. Analysis of data for the branching of this level for some 45 nuclei with $A>56$ indicates agreement with this theory for the ratio $B(E2;2'\rightarrow 2)/B(E2;2'\rightarrow 0)$ within a factor of two for $E_{22}/E_{21}>3$, while for $E_{22}/E_{21}<3$ the correlation is not clearly established. In the case of the ratio $B(E2;2\rightarrow 0)/B(E2;2\rightarrow 0)$, which requires knowledge of the *E2* lifetimes of the first two 2+ levels, the agreement is quite striking, particularly since a quantitative prediction for this ratio is not given by other theories. In the case of the ratio $B(E2;2'\rightarrow 2)/B(E2;2\rightarrow 0)$, preliminary results[3] for six medium weight nuclei indicate good agreement, with the possible exception of Te^{122}. Comparison with the predictions of other theories[4] for this ratio indicates the possibility that for medium-weight nuclei ($E_{22}/E_{21}=2-2.5$) such predictions may be essentially model-independent.

* This research was supported by the United States Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.
[1] A. S. Davydov and G. F. Filippov, Nuclear Phys. **8**, 237 (1958).
[2] D. M. Van Patter, Bull. Am. Phys. Soc. Ser. II, **3**, 360 (1958).
[3] P. H. Stelson and F. K. McGowan (private communication).
[4] G. Scharff-Goldhaber and J. Weneser, Phys. Rev. **98**, 212 (1955); B. J. Raz (to be published).

F10. $Ti^{46}(d,p)Ti^{47}$ and $Ti^{48}(d,p)Ti^{49}$ Angular Distributions.* L. TH. RIETJENS† AND O. BILANIUK,‡ *University of Michigan.*—Thin targets of natural titanium, of TiO_2 enriched to 84% in Ti^{46} and of TiO_2 enriched to 92% in Ti^{48}, have been bombarded by the 7.8 Mev deuterons of the Michigan cyclotron. Resulting angular distributions of magnetically analyzed protons (over-all resolution 35 Kev) have been recorded in 100 η NTB nuclear emulsions. The Ti^{47} ground-state $l_n=3$ transition is ~30 times more intense than the transition to the 0.160 Mev first excited state for angles $\theta_{Lab}=5°$ to 90°. This result favors a $J=7/2$ assignment to Ti_0^{47}, contrary to the accepted value of $J=5/2$. Stripping to the 1.40 Mev state in Ti^{47} leads to an $l_n=1$ capture. Evidence has been found for excited states in Ti^{47} at (0.16 Mev), (0.39 Mev), 1.40 Mev, 1.64 Mev, 2.39 Mev, 2.64 Mev, 3.09 Mev, 3.34 Mev, 3.45 Mev, and at 3.70 Mev. The states in Ti^{49} at 0, 1.35 Mev, 1.70 Mev, and at 3.11 Mev are formed, respectively, via $l_n=3$, $l_n=1$, $l_n=1$, and $l_n=2(1?)$ neutron captures, in agreement with previous low resolution findings.[1]

* Supported in part by the U. S. Atomic Energy Commission.
† Now at FOM Instituut voor Plasma-Fysica, Utrecht, Nederland.
‡ Now with the University of Rochester.
[1] M. M. Bretscher *et al.*, Phys. Rev. **96**, 103 (1954).

F11. (d,p) Reactions in Bismuth and Uranium.* G. B. HOLM,† J. R. BURWELL, D. W. MILLER, AND F. R. SWANSON, *Indiana University.*—A double-focusing magnetic spectrometer has been employed to observe the energy and angular distributions of proton groups from Bi^{209}, U^{235}, and U^{238} targets bombarded by 11-Mev deuterons. The Q value of the most energetic $Bi^{209}(d,p)Bi^{210}$ group, previously unobserved, is found to be 2.34 ± 0.03 Mev. As the ground-state Q value calculated from known binding and disintegration energies is 2.38 Mev, this group may represent either the ground-state or a low excited-state transition, or both. Broad but distinct proton groups were also observed corresponding to groups of states in Bi^{210} with mean excitation energies of 0.41, 0.88, 1.5, 2.02, 2.56, 2.81, 3.15, and 4.03 Mev. Some of the properties of these groups will be compared with previous experimental and theoretical results in the lead region. Measurements on uranium using separated isotopic targets provided by the Los Alamos Scientific Laboratory have also been completed, and Q values for the most energetic proton groups will be quoted.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† On leave from Nobel Institute of Physics, Stockholm.

F12. Angular Distributions of Fragments in the Fast-Neutron Fission of U^{233}, U^{235}, and Pu^{239}.* R. L. HENKEL AND J. E. SIMMONS, *University of California, Los Alamos Scientific Laboratory.*—A multiangle, gas filled counter has been used to investigate the fragment anisotropy for fission induced by 0.5 to 23-Mev neutrons. Coincidences were observed between one fragment entering one of 5 proportional counters—arranged between 0° and 90° with respect to the neutron direction—and the associated fragment entering an ionization chamber behind the foil. The experimental cross-section ratios $\sigma(10°)/\sigma(90°)$ are listed in the following for a few chosen energies:

E_n(Mev)	0.5	1.0	2.0	3.0	4.0	5.0
U^{233}	1.057	1.061	1.104	1.089	1.058	1.100
U^{235}	1.011	1.073	1.191	1.165	1.103	1.183
Pu^{239}	1.048	1.090	1.110	1.130	1.082	1.096.

Uncertainties are about 5% at 1.0 Mev and below, and 3% above this energy. It has been suggested[1] that Pu^{239} should show a larger forward peaking than the other two isotopes. Recent experiments[2] have been cited in favor of this suggestion. Our data, however, do not indicate a trend in this direction. Angular distributions were also measured for Th^{230}, U^{234}, U^{236}, U^{238}, and Np^{237}.

* This work performed under the auspices of the U. S. Atomic Energy Commission.
[1] A. Bohr, *Proceedings of the International Conference on the Peaceful Uses Atomic Energy, Geneva* (1955), Vol. 2, p. 151.
[2] Blumberg, Bahcall, Garrett, and Leachman, Bull. Am. Phys. Soc. Ser. II, **4**, 31 (1959).

F13. Angular Distribution of Fragments from Fission of U^{236} Induced by 6.14 Mev Gamma Rays.* J. P. CONNER, R. L. HENKEL, AND J. E. SIMMONS, *Los Alamos Scientific Laboratory.*—The multi-angle counter described in the preceding abstract was used to examine the angular distribution of fragments from the photofission of U^{236}, which was chosen primarily because of its high cross section.[1] Calcium fluoride targets were bombarded by protons from the Los Alamos Cockcroft-Walton accelerator to produce gamma rays from the 340-kev resonance of the $F^{19}(p,\alpha\nu)O^{16}$ reaction. From this level, 96% of the gamma rays have an energy of 6.14 Mev, with the energy of the remaining gamma rays about 7 Mev.[2] Fission counting rates of about two per hour were observed. The following experimental data were obtained:

θ	10°	22½°	45°	67½°	90°
Fissions	9	22	45	97	90.

Some small geometrical factors and counter efficiency corrections are yet to be applied to these data. A fit to the observed angular distribution of the form; intensity $I(\theta)=a+b\sin^2\theta$ yields a ratio of b/a of roughly 20, suggesting principally dipole interaction of the photon and nucleus.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] K. Clarke, thesis, ANL-5853 (July, 1958).
[2] Chao, Tollestrup, Fowler, and Lauritsen, Phys. Rev. **79**, 108 (1950).

F14. Photofission Cross Sections of Several Heavy Nuclides near Threshold.* J. R. HUIZENGA, J. E. GINDLER, AND R. VANDENBOSCH, *Argonne National Laboratory.*—Gamma rays of 6.14, 6.91, and 7.11 Mev produced by the F^{19} $(p,\alpha\gamma)O^{16}$ reaction were used to induce fission in Th^{232}, U^{233}, U^{234}, U^{235}, U^{236}, U^{238}, and Np^{237}. The CaF_2 target was approximately 200 kev thick to 1.38-Mev protons. The intensities of gamma rays at 0° and 90° produced at proton bombarding energies of 1.56 and 2.10 Mev were measured with a scintillation spectrometer having an anticoincidence annulus.[1] Photofission cross sections of the heavy isotopes measured with an ionization chamber will be reported for 7.0 (6.91 and 7.11 Mev gamma rays) and 6.14-Mev gamma rays. The gamma ray intensity ratios, $I_{6.14}/(I_{6.91}+I_{7.11})$, at the two proton bombarding energies differed by a factor of about 40 and were known much better than the ratios assumed in a similar experiment[2] which employed thick CaF_2 targets.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
[1] C. C. Trail and S. Raboy, Bull. Am. Phys. Soc. Ser. II, **3**, 385 (1958).
[2] K. M. Clarke and J. R. Huizenga, Bull. Am. Phys. Soc. Ser. II, **2**, 377 (1957); K. M. Clarke, ANL-5853 (1958) (unpublished).

F15. Neutron Induced Fission Cross Section of Pu^{242} from 0.1 to 1.5 Mev.* DANIEL K. BUTLER, *Argonne National Laboratory.*—The neutron induced fission cross section of Pu^{242} has been measured relative to the fission cross section of U^{235}. A 230-μg sample of Pu^{242} was mounted back to back with a sample of U^{235} in a double gas scintillation counter. The measurements were made with neutrons from the $Li^7(p,n)Be^7$ reaction produced by protons from a Van de Graaff accelerator. The total neutron energy spread at all energies was less than 60 kev. Corrections were made for spontaneous fission background and for the fission detection efficiency of the scintillators. The fission cross section of Pu^{242} was found to be small below neutron energies of 400 kev. At 400 kev it rises sharply to a value of 1.7 barns at 1.1 Mev. From 1.1 to 1.5 Mev the cross section remains essentially constant.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

THURSDAY AFTERNOON AT 1:45

Willard, Grand Ballroom

(J. AROL SIMPSON presiding)

Electron Physics: Plasma, I

FA1. Electron Capture and Loss by H in H_2.* R. CURRAN AND T. M. DONAHUE, *The University of Pittsburgh.*—Electron capture and loss cross sections ($\sigma_{01}+\sigma_{0-1}$) for hydrogen atoms between 5×50 Kev in H_2 have been measured by a method described elsewhere.[1] ($\sigma_{01}+\sigma_{0-1}$) exhibited peaks at about 10, 18, and 25 kev. Measurement of the difference ($\sigma_{01}-\sigma_{0-1}$) by collecting gas ions and electrons along the beam path, revealed that the peaks persisted in σ_{01}. It is suggested that they represent processes in which the electron is captured to form negative hydrogen ions rather than lost into the continuum. In fact if the cross sections are plotted as functions of laboratory frame velocities the maxima are found to occur at nearly the same velocities for which maxima in the cross section for formation of H^- by electrons in H_2 were measured by Schulz[2] and by Khvostenko and Dukel'skii.[3] This suggests that the first peak is due to H_2O and would explain the great discrepancies in previous measurements of σ_{01}. A by-product of the experiment is the cross section for production of ion pairs in the target gas.

* Supported by the Office of Naval Research.
[1] Curran, Donahue, and Kasner, Phys. Rev. (to be published).
[2] G. J. Schulz, Phys. Rev. (to be published).
[3] V. I. Khvostenko and W. M. Dukel'skii, Zhur. Eksp. i Teoret. Fiz. **33**, 851 (1957); translation in Soviet Phys. JETP **6**, 657 (1958).

FA2. Measurement of the Electron-Potassium Exchange Cross Section by an Atomic Beam Method.* K. RUBIN, J. PEREL, AND B. BEDERSON, *New York University.*—Direct observations of the exchange of slow electrons with the potassium valence electron have been made. The method used involves the cross firing of a polarized potassium beam with an electron beam. Conventional inhomogeneous magnets are used to polarize and analyze the potassium beam. The analyzer magnet is mounted so as to rotate about the scattering center, since the potassium beam suffers a recoil as a result of the scattering. Ratios of exchange to total scattering signals at

various atom recoil angles have been obtained for electron energies ranging from 0.5 to 4 ev. From these data, upper and lower bounds on the exchange cross section Q_e may be inferred. For example, at 0.5 v, the bounds on Q_e are 0.8×10^{-14} cm^2 $<Q_e<1.6\times10^{-14}$ cm^2, in agreement with the upper bound obtained by Franken *et al.*[1] for the thermal electron-potassium exchange cross section. The ratio of exchange to total cross section over the 0.5 to 4 ev region is about 0.3, to within a factor of two.

* Supported by the Office of Naval Research.
[1] Franken, Sands, and Hobart, Phys. Rev. Letters 1, 52 (1958).

FA3. Resonance Phenomena in Large-Angle He^+ on He Collisions.* F. P. ZIEMBA AND E. EVERHART, *University of Connecticut.*—Previous investigations[1,2] of large-angle scattering from He^+ on He collisions at 25, 50, and 100 kev demonstrated two interesting facts. First, there was little variation to the charge state fractions (He^0, He^+, He^{++}) of the scattered incident helium particle as a function of scattering angle. Second, the fraction scattered as He^0 (electron capture) was unexpectedly higher at 50 kev than at 25 or 100 kev. A detailed investigation of the second phenomenon over the energy range of 2 to 250 kev clearly shows electron capture to be an energy dependent resonance process. The fraction of the scattered incident particle which is neutral after a 5° scattering shows maxima at 2.7, 4.0, 5.8, 9.6, 17.5, and 43 kev and indications of a maximum at about 250 kev. The fraction scattered as He^{++} shows peaks at 80, 26, and 13.5 kev. Peaks for He^{++} occur where the fraction scattered as He^0 is a minimum.

* Sponsored by the Office of Ordnance Research, U. S. Army.
[1] Fuls, Jones, Ziemba, and Everhart, Phys. Rev. **107**, 704 (1957).
[2] Jones, Ziemba, Moses, and Everhart, Phys. Rev. **113**, 182 (1959).

FA4. Energy Distribution and Fragmentation Processes Resulting from Electron Impact on Hydrocarbons.* M. S. KAMINSKY AND W. A. CHUPKA, *Argonne National Laboratory.*—Ionization efficiency curves have been measured for the most abundant ions produced by electron impact on propane. The second derivatives of these curves have been used to determine (1) the energy distribution of the parent molecular ions before fragmentation and (2) the experimental breakdown curves. The results are in qualitative agreement with the theoretical calculations of Rosenstock *et al.*[1] based on the statistical theory of mass spectra. However, the agreement is quantitatively inadequate and a comparison indicates that the energy distribution used by Rosenstock *et al.* is considerably too wide and that his calculated breakdown curves vary too slowly with energy. These conclusions are in agreement with the work of Chupka[2] on photoionization of *n*-propanol. Preliminary data of the same type for *n*-butane and other hydrocarbons will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Rosenstock, Wallenstein, Wahrhaftig, and Eyring, Proc. Natl. Acad. Sci. U. S. **38**, 667 (1952).
[2] W. A. Chupka, J. Chem. Phys. **30**, 191 (1959).

FA5. Range of Monoenergetic Electrons in Carbon, Aluminum, Copper, Tantalum, and Glass. MARK J. JAKOBSON, *Montana State University.*—The range of monoenergetic electrons ($\Delta P/P=1\%$) in various materials has been measured for electrons of energy from 1.8 to 7.0 Mev. The monoenergetic electrons were obtained by sending electrons from a linac through an analyzer magnet which had been calibrated by means of the floating wire technique to an accuracy of 0.1%. Microscope cover glasses of 0.04 g/cm^2 were used as detectors. Approximately 0.2 microcoulomb/cm^2 of electrons in the foregoing energy range was sufficient to cause the glass to be visibly darkened. Exposures with an auxiliary magnet indicated that the penetration of the electrons could be identified with the darkening of the glass. Measurements by this technique indicate that the extrapolated ranges in C, Al, glass, and Ta differ. For 5.0-Mev electrons, the extrapolated ranges are C, 2.64 ± 0.08; Al, 2.52 ± 0.08; glass, 2.34 ± 0.12; Ta, 2.12 ± 0.08 g/cm^2. The effect of multiple scattering is evident and in agreement with previous experiments.[1] Maximum and extrapolated ranges in the above listed materials will be presented.

[1] F. L. Hereford and C. P. Swann, Phys. Rev. **78**, 727 (1950).

FA6. Improved Electron Filter Lens. L. MARTON AND J. A. SIMPSON, *National Bureau of Standards.*—Symmetrical electrostatic electron lenses, with the saddle point lying very close to cathode potential, have the useful property that only electrons, which have not lost appreciable energy, are transmitted. In the early work of Boersch[1] this cutoff was made reasonably sharp by the use of small apertures (<0.3 mm) or meshes at the center electrode. Both these expediencies reduce the transmission of the lens. At usable apertures cutoffs of a few electron-volt width were obtained with focal lengths limited by the design to less than 5 mm. By use of an intermediate focus, it is possible to obtain cutoffs less than 0.5 ev wide with any desired focal length and high transmission. The details of one such lens will be discussed.

[1] H. Boersch, Z. Physik **134**, 156 (1953).

FA7. Search for Polarization in Photoelectrons from Ferromagnetic Films. H. A. FOWLER AND L. MARTON, *National Bureau of Standards.*—Photoelectrons from thin films of iron, nickel, and cobalt with strong permanent magnetization have been examined for spin polarization. Longitudinal electrostatic acceleration to 120 kev and Mott scattering at 85° from gold foils comprise the method of detection. The observations indicate polarization asymmetry to be not larger than 5%. The cathode film has been prepared by evaporation onto the optically polished end of a rock salt cylinder, and annealing in a vacuum oven with a 250-gauss field parallel to the plane of the film. It exhibits strong permanent magnetization. Under strong uv radiation a beam is obtained in the Mott scattering apparatus.[1] The magnetized cathode film is rotated in its plane, normal to the electron beam axis, to examine azimuthal asymmetry with a fixed detector. Comparison scattering with aluminum foils permits instrumental asymmetry, of the order of 5 to 10%, to be removed. Minimum detectable polarization asymmetry, which is fixed by background scattering, is estimated at 5%. Possible interpretations will be discussed.

[1] Fowler, Marton, and Quinn, Bull. Am. Phys. Soc. Ser. II, **3**, 264 (1958).

FA8. Surface Plasma Oscillations and the 7 ev Loss in Aluminum.* EDWARD A. STERN, *University of Maryland.*—Electrons, with energies in the tens of kev, after passing through thin films show discrete energy loss lines. For aluminum these losses occur at 7 ev, 15 ev, and multiples and sums of these two values. The 15 ev loss is caused by excitation of bulk plasma oscillations but there is some controversy over the origin of the 7 ev loss. A natural explanation of the 7 ev loss is excitation of Ritchie's[1] surface plasma oscillations. When the oxide coating that exists on Al films is taken into account the energy of the surface modes is lowered to 7 ev. With the oxide coating thickness varying between 20 A to 50 A the intensity of the 7 ev loss for a 400 A thick Al film is calculated to be between 5 to 10% of the 15 ev loss intensity in agreement with experiment. Strong evidence for this explanation is furnished by the experimental detection of surface plasma oscillations in anomalous diffraction gratings as discussed by Fano.[1] An experiment is suggested to test this proposed explanation of the 7 ev loss in aluminum.

* Research supported by the National Security Agency.
[1] R. H. Ritchie, Phys. Rev. **106**, 874 (1957); U. Fano, J. Opt. Soc. Am. **31**, 213 (1941).

FA9. Electron Densities in Plasmas from the Broadening of Allowed and Forbidden Helium Lines.* H. GRIEM, *University of Maryland and U. S. Naval Research Laboratory.*—Helium lines emitted from high-density plasmas are mainly broadened by the interaction of the radiating atoms with the electric fields produced by the electrons and ions. For static fields many of the lines exhibit a quadratic Stark effect. Previous theories employ static Stark effect coefficients to derive line profiles and in certain cases yield line widths that are too large by nearly an order of magnitude than observed widths.[1] A recently developed electron impact theory[2,3] for overlapping lines was therefore applied to He 3964.7 A (2^1S-4^1P) which overlaps with the forbidden line (2^1S-4^1F). The quasi-static fields produced by ions also enhance the forbidden component because they give rise to a mixing of the upper states. Since the theory presented here predicts the detailed structure of this complicated line profile with a forbidden component, it can be used to determine electron and ion densities from measured line profiles with an accuracy of 20%.

* Jointly supported by GRDC and Office of Naval Research.
[1] H. Wulff, *Z. Physik* **150**, 614 (1958).
[2] M. Baranger, *Phys. Rev.* **111**, 494 (1958).
[3] A. C. Klob and H. Griem, *Phys. Rev.* **111**, 514 (1958).

FA10. Use of Flames for Plasma Research.* JÜRGEN SCHNEIDER, F. W. HOFMANN, AND HEDWIG KOHN, *Duke University.*—Flames can be used to study the electromagnetic properties of partially ionized gases on a moderate scale. One advantage of this method arises from the fact that the electron concentration N and the collision frequency ν, two fundamental quantities of an ionized gas, can be varied independently over a wide range. When sprays of alkali salt solutions are introduced into a flame, partial thermal ionization of the alkali atoms occurs, and the electron concentration N is a function of the salt concentration in the solutions. Furthermore, the electron collision frequency ν can be varied by burning the flame in a closed vessel under variable pressure. Measurements of the electric conductivity between 23.10 and 92.96 kMc/sec indicate that the effective electron-molecule collision frequency in an acetylene-air flame is independent of the electron velocity within the limits of error. Electron concentrations in the flame gases were obtained. Cyclotron resonance of free electrons has been found[1] in low-pressure flames at 24 kMc/sec. This effect can also be used to determine both the concentration of free electrons and the electron collision frequency.

* This research was supported by the Office of Scientific Research, the U. S. Air Force, and the Office of Naval Research.
[1] J. Schneider and F. W. Hofmann, *Phys. Rev. Letters* **1**, 408 (1958).

FA11. High-Frequency Plasmoids.* ALBERT J. HATCH, *Argonne National Laboratory.*—A phenomenological explanation of major features of the low-pressure high-frequency plasmoid mechanism will be presented. Throughout the major body of the plasmoid the applied rf field is strongly attenuated, substantial penetration occurring only in the narrow boundary sheath. An electron cloud executes forced oscillations within the plasmoid. The velocity of a typical electron inside the plasmoid is approximately uniform except in the sheath where velocity reversal is caused by the penetrating E field. The sheath constitutes a virtual electrode isolating the oscillating electron cloud from the less luminous plasma in which the plasmoid is immersed. Phase coherence of the oscillating cloud is possible since the collision frequency is small compared to the oscillation frequency. A significant difference between the electron oscillations in plasmoids and those in Langmuir type plasma oscillations is that the former are forced whereas the latter are harmonic. The approximately constant ionization rate throughout the main body of the plasmoid and the reduced rate in the sheath are consistent with the luminous appearance of the plasmoid. The experimental observation of a sheath thickness which is small compared to the electron mean free path is also consistent with the present explanation.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

FA12. Experimental Studies in Plasma Dynamics.* S. KOSLOV, WINSTON H. BOSTICK, M. ROSMARYNOWSKI, G. SCHMIDT, AND J. E. NANKIVELL, *Stevens Institute of Technology,* AND A. GRUMET, *Republic Aircraft Corporation.*—A new technique for measuring the mass of a plasmoid projected across a magnetic field employs an electromagnetic brake. Plasmoid masses of the order of 10^{-9} g can readily be measured. The electromagnetic brake places the plasmoid in a decelerated frame of reference. A bipolar probe technique has been developed for measuring not only the electric field associated with the Lorentz transformation but the electric field due to the decelerated frame of reference. The bipolar probe technique can also be used to measure ion densities over small volumes, and can be used to verify previous measurements which indicated that under some conditions hollow plasmoids can be produced. Measurements with this technique indicate that hollow plasmoids do not spin. These results lay to rest the previous hypothesis[1] that spin is responsible for the hollowness of plasmoids.

* Work supported by the Office of Scientific Research, the U. S. Atomic Energy Commission, the U. S. Air Force Cambridge Research Center, and the Republic Aircraft Corporation.
[1] W. H. Bostick, *Phys. Rev.* **104**, 992 (1956); **106**, 404 (1957).

FA13. Acceleration of a Plasma by Means of a Rail Type Gun.* G. SCHMIDT, WINSTON H. BOSTICK, J. E. NANKIVELL, AND S. KOSLOV, *Stevens Institute of Technology,* AND R. L. SMALL AND C. H. KELLEY, *Grumman Aircraft Corporation.*—The principle and operation of a rail type plasma gun is described. An electric discharge ionizes the gas in the gun while the em field of the discharge circuit accelerates this plasma along the rails projecting it into a high vacuum region. Velocity and momentum measurements are made in this region with time-of-flight between two probes for the velocity and a ballistic pendulum measurement for the momentum. High plasma speeds are observed. Some possible applications of fast plasmas are discussed.

* Work supported by the U. S. Atomic Energy Commission, the Office of Scientific Research, and the General Electric Company.

FA14. Unstable Plasma Oscillations in a Magnetic Field. E. G. HARRIS, *The University of Tennessee and Oak Ridge National Laboratory.*—The small amplitude oscillations of a fully ionized quasi-neutral plasma in a uniform time independent externally produced magnetic field are discussed on the basis of the Vlasov equations. Perturbations of the magnetic field are neglected. It is shown that anisotropies of the velocity distribution functions can lead to instabilities. If the components of velocity perpendicular to the field have a Maxwellian distribution and there is a zero spread in the velocities along the field, then it is found that unstable oscillations occur when the electron plasma frequency becomes greater than the ion cyclotron frequency. Other unstable modes of oscillation occur when the electron plasma frequency becomes greater than the electron cyclotron frequency.[1]

[1] E. G. Harris, *Phys. Rev. Letters* **2**, 34 (1959).

THURSDAY AFTERNOON AT 2:00

Commerce Auditorium

(S. E. FORBUSH presiding)

Cosmic Rays, II, Mainly Primaries

G1. Proton Component of the Primary Cosmic Radiation.* WILLIAM R. WEBBER, *University of Maryland*, AND FRANK B. MCDONALD, *State University of Iowa*.—The proton component has been extensively studied at high altitudes on a series of 6 skyhook balloon flights at various latitudes using the Čerenkov-scintillation counter technique during the period 1955–1957. The intensity of primary protons has been measured at 4°, 41°, 53°, and 55° geomagnetic latitude. The proton differential energy spectrum has been measured directly in the region 250–750 Mev. It is observed that primary alphas and protons have the same form of rigidity spectrum from 1 BV to 15 BV. A series of cutoff rigidities are measured in the vicinity of $\lambda = 53°$ and 55°. The intensity and composition of fast splash albedo is determined at $\lambda = 4°$, 53°, and 55°. Differences observed in the intensity and energy spectra of the three high latitude flights are discussed and strong restraints are placed on possible modulating mechanism.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

G2. Further Studies of the Long-Term Temporal Variation of the Primary Cosmic Radiation.* FRANK B. MCDONALD, *State University of Iowa*.—A further series of skyhook balloon flights have been made during the period of 1958–1959 near solar maximum. These flights were launched from $\lambda = 41°$, 49°, and 55°. The flux and energy spectrum from alpha particles has been determined in the region 150 to 1500 Mev/nucleon. The proton flux and energy spectrum has been determined from 300 Mev to 3500 Mev. Also the Geomagnetic cutoff energy at $\lambda = 49°$ has been directly determined. A study of the changes in the energy spectra of these two charge components furnishes additional information regarding the nature of the long-term modulating mechanism.

* Assisted by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.

G3. Intensity Changes of Cosmic Rays as Determined by a Meson Telescope of Solid Angle 1.2×10^{-3} Steradians. J. KATZMAN, *National Research Council, Ottawa*.—Analysis of the cosmic-ray intensity obtained by means of a meson telescope of solid angle 1.2×10^{-3} steradians with 96 in. of lead absorber for the period January, 1955, to December, 1958, shows a change in correlation of the diurnal and semidiurnal components from negative to positive. This apparent correlation with pressure can be explained by a change in the hourly intensities with the greatest change taking place in the 16th hour, from 115% of the yearly mean in 1955 to 85% in 1958. This explains Rau's[1] published result of a positive correlation for the second harmonic of the cosmic ray intensity with the second harmonic of the atmospheric pressure. The sun's activity was at a maximum in 1937–38 as it is in 1958 and the polarity of the sunspots was the same in 1938 as in 1958. The average intensity is shown to increase by 20% from 1955 to 1958 with increase in solar activity.

[1] W. Rau, Z. Physik **265**, 114 (1939).

G4. Modulation of Cosmic Rays During the Solar Cycle.* E. P. NEY AND P. S. FREIER, *University of Minnesota*.—Alpha-particle differential energy spectra have been measured eight times during the last solar cycle. Two flights at solar minimum in 1954 and 1956 have shown spectra with maxima in the differential flux at an energy of 250 to 300 Mev/nucleon. In these flights total fluxes of 290 particles/m² sec ster were observed. At solar maximum during 1957 and 1958 the results indicate that the maximum in the energy spectrum has disappeared or has been displaced to lower energies. The total fluxes during this active period are between 120 and 150 particles/m² sec ster and the energy spectra show a monotonic increase at low energies down to 130 Mev/nucleon. Although the total intensity has decreased as the solar activity has increased, the reverse is true at low energies. At energies below 200 Mev/nucleon increased solar activity is accompanied by increased fluxes. The solar cycle modulation has a steeper energy dependence than the Forbush decrease modulation indicating a fundamental difference between these effects.

* This work was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission, and by the U. S. National Committee for the IGY through the National Science Foundation.

G5. Cosmic Ray Protons from the Sun.* P. S. FREIER, E. P. NEY, AND J. R. WINCKLER, *University of Minnesota*.—A series of flights made in Minnesota during late March, 1958, have shown that during a Forbush decrease on March 26, low-energy protons (135 to 185 Mev) arrived at an altitude of 100 000 ft in high intensity. Measurements of total ionization and counting rate of a single counter show that during the flight of March 26 the intensity increased from the normal value for this period, and that the time dependence of this increase closely resembled the time dependence of a simultaneous magnetic bay. Photographic emulsion measurements have shown that the increase observed is due to protons in the rigidity range of 0.55 to 0.62 BV. Both higher and lower rigidity protons may have also arrived but could not be observed because of instrumental and air cutoffs. The flux of protons in the energy interval 130 to 180 Mev was 0.09 particle/cm² sec ster. A possible interpretation of this event is that these protons are carried to the earth in a magnetic cloud. It is believed that they could not have come directly from the sun because of the absence of a flare at the time of the intensity increase and because their energies are below the cutoff energy appropriate to our latitude.

* This work was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission, and by the U. S. National Committee for the IGY through the National Science Foundation.

G6. Solar Activity and the Primary Cosmic-Ray Intensity.* S. P. AGARWAL, M. A. POMERANTZ, AND V. R. POTNIS, *Bartol Research Foundation*.—A series of simultaneous balloon flights was conducted at Swarthmore, Pennsylvania ($\lambda = 52°$N) and Tallahassee, Florida ($\lambda = 42°$N), during a period (July 24–26, 1958) characterized by a reduced primary cosmic-ray intensity at the former station.[1] Within the experimental uncertainties, the primary flux at Tallahassee (as measured with quadruple-coincidence counter trains containing 7.5 cm of interposed Pb) agreed with that expected on the basis of observations during a period of normal intensity. The latitude variation of the measured flux was consistent with expectation in terms of the imposition by a solar-associated modulating mechanism of a sharp cutoff in the magnetic-rigidity spectrum unaccompanied by an appreciable change in the spectrum just above this minimum.[2]

* Assisted by the U. S. National Committee for the IGY and by the Office of Naval Research.

[1] Pomerantz, Agarwal, and Potnis, Phys. Rev. Letters **1**, 65 (1958).

[2] M. A. Pomerantz and S. P. Agarwal, Phys. Rev. Letters **1**, 107 (1958).

G7. Observations of Low-Energy Solar Cosmic Rays from the Flare of August 22, 1958. Part I. K. A. ANDERSON, *State University of Iowa*, AND R. ARNOLDY, R. HOFFMAN, L. E. PETERSON, AND J. R. WINCKLER, *University of Minnesota*.—On August 22, 1958, a large flux of protons having energy too low to produce ground level effects was observed during a balloon flight at Fort Churchill in association with a solar radio noise storm of unusual intensity and duration.[1] Vertical unidirectional fluxes 20 to 30 times the normal cosmic ray level were measured. From the fact that no effects were detectable in a simultaneous flight over Minneapolis, limits can be placed on the abundance of neutral radiations. The results are that high-energy photons constitute less than 10% of the observed flare radiation while the limit for neutrons of energy greater than 100 Mev is 5%. The absence of neutrons indicates that nuclear processes are unimportant in the production of these low-energy solar cosmic rays. Electrons of energy above 100 Mev are admitted magnetically at Churchill but the data show that their energy spectrum, while unobserved, must lie considerably below the proton spectrum. The proton differential energy spectrum is derived from ionization *versus* atmospheric depth data and is found to be $n(E)dE = K(t)E^{-5.0\pm0.2}dE$. This applies in the energy range 100 to 400 Mev.

[1] K. A. Anderson, Phys. Rev. Letters 1, 335 (1958).

G8. Observations of Low-Energy Solar Cosmic Rays from the Flare of August 22, 1958. Part II.* J. R. WINCKLER, L. E. PETERSON, R. HOFFMAN, AND R. ARNOLDY, *University of Minnesota*, AND K. A. ANDERSON, *State University of Iowa*.—The flare-accelerated particles discussed in the previous paper were observed at Fairbanks, Alaska, on a balloon flight reaching high altitude 15 hr after the first intense burst recorded at Churchill. The particles penetrated into the atmosphere to a depth of at least 30 g/cm², and had an integral number—energy spectrum similar to the Churchill spectrum varying as E^{-5}. The intensity at Fairbanks was considerably less than observed at Churchill at about the same time. These particles decreased in intensity but were still present 19 hr later and it must be assumed that they were stored in space near the earth during this period. Thirty-six hours after the Churchill burst a magnetic storm and auroral phenomena occurred. This was accompanied by a depression of cosmic rays observed by further balloon flights at Fairbanks and Minneapolis, and by sea level neutron monitors. The intensity decrease completely removed the residual low-energy stored particles incident at Fairbanks and also attenuated cosmic rays of much higher energy. One must assume that the solar flare which injected low-energy cosmic rays into space also generated a solar gas cloud, and that the passage of this cloud near the earth removed or prevented the further influx of the flare particles.

* This work supported by the U. S. National Committee for the IGY through the National Science Foundation and by the Office of Naval Research.

G9. Satellite Observations of Time Variations of Charged Particle Intensities at High Latitudes. CARL E. MCILWAIN AND PAMELA ROTHWELL, *State University of Iowa*.—The intensities of charged particles, measured with an unshielded and a shielded Geiger counter in satellite 1958ε (Explorer 4), increased by one to two orders of magnitude on three occasions (August 16–17, 23–24, and 26–27, 1958), at altitudes of ~300 km above the earth's surface and latitudes near the auroral zone. These increases began in each case the day before a magnetic storm. The minimum proton energies needed to penetrate the shielded and unshielded counters are 40 Mev and 30 Mev, respectively, and the minimum electron energies are 5 Mev and 3 Mev. The August 23–24 event is probably associated with the high latitude "solar flare" increase in particle intensity observed at balloon altitude by Anderson.[1]

[1] K. A. Anderson, Phys. Rev. Letters 1, 335 (1958).

G10. Gamma-Ray Burst from a Solar Flare.* L. E. PETERSON AND J. R. WINCKLER, *University of Minnesota*.—A burst of high-energy radiation coincident with a solar flare[1] has been detected during a balloon flight for the IGY. The flare occurred at 1305 U.T. March 20, 1958 and was associated with solar radio bursts on 1500 and 10 000 mc, and terrestrial effects including an SID, earth current disturbance, and magnetic crotchet. The 18-sec burst was detected with an integrating ionization chamber and a single Geiger counter at 10 g/cm² and 30° geomagnetic latitude. From these measurements and their ratio, it is inferred that the radiation is due to a gamma-ray flux of about 2×10^{-5} ergs/sec-cm² peaked in the 200 to 500-kv region. This radiation can be interpreted as Bremsstrahlung from ½ to 1-Mev electrons stopping in the solar photosphere. These same electrons, spiralling in a 1000 gauss field in the flare region, can produce the observed radio burst by betatron radiation. The high-energy electrons represent about 1% of the flare energy, and only about 10^{-4} of the emitted betatron escaped from the flare region toward the earth.

* This work supported by the U. S. National Committee for the IGY through the National Science Foundation, and by the Office of Naval Research.

[1] L. E. Peterson and J. R. Winckler, Phys. Rev. Letters 1, 205 (1958).

G11. On the Trapping of Particles in the Geomagnetic Field. ERNEST C. RAY, *State University of Iowa*.—Trapping of charged particles interacting with an atmosphere in a pure dipole magnetic field is discussed. An approximate expression for the mean atmospheric density along a particle trajectory is obtained. Impulsive particle input, as from geomagnetic storms or solar flare particles, and continuous input, as from cosmic ray neutron decay, both during the approach to equilibrium and at equilibrium are considered. It seems very unlikely that the spatial dependence of the radiation observed in satellites 1958α, 1958γ, 1958δ, and 1958ε is caused by anomalies in atmospheric absorption or scattering effects.

G12. Cosmic-Ray Anisotropy Studies at Low Latitudes.* P. D. BHAVSAR AND V. L. PATEL, *Physical Research Laboratory, Ahmedabad, India* (introduced by J. R. Winckler).—Narrow angle meson telescopes at low latitudes record particles from known directions in space because of the well-defined trajectories for the primaries (mean rigidity about 30 BV) responsible for the observed μ mesons. A study of the solar correlated anisotropy, revealed by the diurnal variation on individual days observed with such telescopes, showed that for the period 1954–55 the diurnal variation on individual days was either of two types, the hours of maxima being 0300 and 1100 hr local time for "*n*" and "*d*" types, respectively. A similar study for the period 1956 showed a shift in these times to 0700 hr for the "*n*" type and 1500 hr for the "*d*" type. We now have investigated this shift and the relative frequency of occurrence of the "*n*" and "*d*" type days for the period September, 1954, to December, 1957. It is observed that with the advance of the present solar cycle of activity, the hours of maxima gradually shift towards the later hours with a relative increase in the "*n*" type days. By the end of 1957, the "*n*" type maxima shift so much that they occur at the same time where "*d*" type maxima occurred in 1954. An increasing spread in the distribution of occurrence of the diurnal maxima is observed with the advance of the solar cycle.

* Supported by the Dept. of Atomic Energy, Govt. of India.

THURSDAY AFTERNOON AT 2:00

Willard, South Ballroom

(J. G. DAUNT presiding)

Cryogenics, II; Liquid Helium

GA1. Heat Flow in He II. J. W. HENDERSON AND J. E. MERCEREAU, *Hughes Research Laboratories.*—The temperature difference, ΔT, between a constant temperature bath and a totally immersed cavity have been measured below the λ point. The cavity is connected to the bath by a cylindrical tube with an inside diameter on the order of a millimeter. For a particular measurement a constant power $\dot{Q}$ is supplied electrically to the cavity and the resultant behavior of ΔT recorded *versus* time. Three regions of interest are found. The first, $\dot{Q}<\dot{Q}_c$ watt/cm^2, the behavior is explainable on the basis of a surface and mutual friction. For a small region in $\dot{Q}$ above $\dot{Q}_c$ a low-frequency relaxation oscillation of ΔT is found. For larger $\dot{Q}>\dot{Q}_c$ the equilibrium value of ΔT is largely independent of $\dot{Q}$. Data will be presented for several different tube length and radius combinations, as a function of bath temperature. The behavior of second sound in the cavity will be discussed.

GA2. Flow Measurements in Liquid He II.* J. N. KIDDER AND W. M. FAIRBANK, *Duke University.*—A sensitive apparatus has been built for studying flow in liquid He II. A 1-mm capillary is used for the flow channel with two superconducting tin cavities acting as standpipes for measuring pressure gradients. If a cavity is partially filled with liquid helium a 1-A change in the level will change the resonant frequency by 1 cy. Superfluid helium is caused to flow by passing a current through a heater in an insulated chamber at one end of the channel. The other end of the channel is open to the bath. Both ends of the channel are isolated by superfluid filters. The flow has been studied by two methods. In the first method the frequency of a klystron oscillator is swept past the cavity resonance. The shift of the cavity resonance caused by a level change is observed on an oscilloscope. In the second method a klystron is stabilized to each cavity with a modified Pound stabilizer and beat note variations are observed. With the first method the helium level can be measured to 10^{-6} cm. The second method is electronically capable of measuring the level to 10^{-7} cm. In experiments to date the random fluctuations of the helium level were of the order of 10^{-5} cm at optimum conditions.

* This work has been supported by the Research Corporation and the Office of Ordnance Research, U. S. Army.

GA3. Flow of He II Through Narrow Slits. I. Heat Conduction.* EDWARD F. HAMMEL, JR., AND WILLIAM E. KELLER, *Los Alamos Scientific Laboratory.*—The heat flux parallel to the axis of a narrow annulus of He II has been measured as a function of the temperature difference between the slit ends. With one end of the slit maintained at a fixed reference temperature the heat flux $\dot{Q}$ was determined at a series of intermediate temperatures between T_{ref} and T_λ. Twelve different reference temperatures between 1.1 and 2.1°K were investigated. The slit was constructed from an outer cyclinder and centered plug of stainless steel so as to yield an accurately defined slit geometry. Two slits with differing slit widths were employed. The slit dimensions were: length 1.9-cm, annulus circumference 1 cm, slit width (a) 2.1 and (b) 3.4 μ. Using the standard heat flow equations, limiting values of $\dot{Q}/\Delta T$ as $\Delta T \rightarrow 0$ were used to calculate the liquid viscosity. The results are in essential agreement with those obtained in bulk liquid helium except at low temperatures where mean free path effects become observable. At large temperature differences the heat flux becomes almost independent of further increase in ΔT.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

GA4. Flow of He II through Narrow Slits. II. Fountain Pressure Measurements.* WILLIAM E. KELLER AND EDWARD F. HAMMEL, JR., *Los Alamos Scientific Laboratory.*—Coincident with measurements of the heat flow in He II, described in the previous abstract, we have observed the fountain pressures, P_f, associated with the temperature differences between ends of the slit. In addition to the 2.1-μ and 3.4-μ slits, a 0.3-μ slit was also used. Results for the smallest slit are in good agreement with values calculated from the integrated H. London relation, $P_f=\int \rho S dT$ (ρ=density and S=entropy of liquid He II). Observed values of P_f deviate from this relation at progressively lower temperatures as the slit-width is increased. The results also indicate the validity of the Allen-Reekie Rule when the relationship between P_f and the heat current is integrated over the temperature interval. From the observations of P_f near the λ-point temperature we can determine dT_λ/dP for $P<$atmos. We find this to be -0.033 deg/atmos in disagreement with the usually accepted value of -0.012 deg/atmos. but in qualitative agreement with the results found in another heat-flow experiment.[1]

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] Reppy, Burnham, Spees, and Reynolds, Proceedings of the Fifth International Conference on Low-Temperature Physics and Chemistry, Madison, Wisconsin, 1957.

GA5. Flow of He II through Narrow Slits. III. Calculations for Large Temperature Gradients.* P. P. CRAIG, R. LAZARUS, EDWARD F. HAMMEL, JR., AND WILLIAM E. KELLER, *Los Alamos Scientific Laboratory.*—Fountain pressure and heat current have been calculated as functions of temperature and temperature gradient for the flow of He II through slits with zero momentum transfer. The nonlinear two fluid equations of motion were integrated for a wide range of temperature differences across the slit and initial temperatures. An integral equation for the flow has been derived and numerical solutions obtained on an IBM 704 computer. The Gorter-Mellink dissipation term is used with the bulk values of the Gorter-Mellink constant obtained by Vinen. Integration and the use of the Gorter-Mellink term lead to results which reduce to the usual forms in the small gradient limit (linear region) and large gradient limit (cube-root region). Calculated fountain pressures and heat currents agree with observations on 2.1-μ and 3.4-μ slits of 1.9-cm length to within better than 15% over a wide range of temperatures and temperature gradients. The applicability to thin slits of bulk measurements of the Gorter-Mellink constant and the agreement with experiment obtained using the Gorter-Mellink approach suggest that in steady-state flow at high power inputs the relative velocity of superfluid and normal fluid (v_s-v_n) is the determining factor in flow resistance.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

GA6. On the Minimum in the Melting Curve of Liquid He^3.* D. M. LEE, H. A. FAIRBANK, AND E. J. WALKER, *Yale University.*—The blocked capillary method[1] of measuring the

melting curve of He^3 does not allow a distinction between a negative value and a constant value of dp/dT in the region near 0°K. This ambiguity has been resolved by using the change in dielectric constant on freezing to determine the phase of a He^3 sample. At temperatures below 0.32°K when pressures above 29.1 atmos were applied to the sample, the capillary fill line leading to the sample chamber blocked but the helium in the chamber itself remained liquid. Above 0.32°K, the helium in the sample chamber solidified immediately on application of pressure. This implies a negative value of dp/dT and a higher entropy in the solid than in the liquid phase below 0.32°K in agreement with the thermal measurements of Fairbank and Walters.[2] The melting curve above the minimum was found to be in agreement with the results of the Argonne Laboratory.[1] Measurements of the density of liquid He^3 have been extended to 0.15°K and to pressures near the melting pressure and will be discussed.

* Assisted by the National Science Foundation and the Office of Ordnance Research.
[1] Wienstock, Abraham, and Osborne, Phys. Rev. **85**, 158 (1952).
[2] W. M. Fairbank and G. K. Walters, Symposium on Liquid and Solid He^3, Ohio State University, August, 1957.

GA7. Diffusion and Relaxation in He^3 to 0.5°K. H. A. REICH AND R. L. GARWIN, *IBM Watson Laboratory.*—By use of a He^3 refrigerator[1] we have extended our measurements[2] of diffusion constant D and spin relaxation time T_1 to 0.5°K in pure He^3 and in dilute solutions of He^3 in He^4. We have also measured the susceptibility of the 2% solution to 0.5°K. In pure He^3, D is independent of temperature at the lowest temperature reached, while in this same region the viscosity varies as $T^{-\frac{1}{2}}$ or faster.[3] The freezing out of rotons and the subsequent He^3-He^3 scattering is observed in dilute solutions. D fits an equation of the form $D^{-1}=714T+2.4\times10^7\exp(-13.7/T)$. The low temperature behavior of D, varying as T^{-1}, is in contradiction to the expected[4] $T^{\frac{1}{2}}$.

[1] H. A. Reich and R. L. Garwin, Rev. Sci. Instr. **30**, 7 (1959).
[2] R. L. Garwin and H. A. Reich, Bull. Am. Phys. Soc. Ser. II, **3**, 133 (1958).
[3] K. N. Zinovieva, Soviet Phys. JETP **34**(7), 421 (1958).
[4] A. Akhiezer and V. Aleksin, Dokl. Akad. Nauk. SSSR **92**, 259 (1953).

GA8. Pressure-Volume-Temperature Relations of Liquid He^3.* R. H. SHERMAN AND F. J. EDESKUTY, *Los Alamos Scientific Laboratory.*—PVT measurements have been made for liquid He^3 from 1.0–3.3°K and from saturation pressure to the melting pressure. The locus of the zero of coefficient of expansion[1] has been accurately determined by direct observation. This locus intersects the melting curve at 1.26°K and 47.3 atmos. Related thermodynamic functions have been computed and will be presented.

* Work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] Hammel, Sherman, Kilpatrick, and Edeskuty, Physica **24**, S 1-8 (1958).

Post-Deadline Papers, If Any

THURSDAY AFTERNOON AT 1:45

National Bureau of Standards, East Building

(G. T. RADO presiding)

Magnetism and Ferroelectricity

H1. Electron Spin Susceptibility in Lithium. R. HECHT AND A. G. REDFIELD, *IBM Watson Laboratory.*—The spin susceptibility of the conduction electrons in lithium metal has been measured by detecting the change in $\langle M_z\rangle$, the time-average magnetization along the polarizing field direction,[1] when the sample is saturated with square-wave modulated rf power. The samples (metallic dispersions) were chemically analyzed to determine the quantity of lithium metal present.[2] The preliminary result, $\chi=(1.96\pm0.1)\times10^{-6}$ cgs volume units is in reasonable agreement with the measurement of Schumacher and Slichter.[3] The polarizing field, H_0, was 10.6 gauss, and since the linearly polarized rf field amplitudes used were of comparable magnitude, it was necessary to solve the modified Bloch equations numerically to determine the degree of saturation. It was predicted and observed with good agreement that $\langle M_z\rangle$ does not diminish monotonically with increasing rf amplitude, but performs sizable excursions. At the frequency $\omega=\gamma H_0$, the first minimum occurs when the rf amplitude is roughly equal to the polarizing field.

[1] G. Whitfield and A. G. Redfield, Phys. Rev. **106**, 918 (1957).
[2] M. Berkenblit and A. Reisman (to be published).
[3] R. T. Schumacher and C. P. Slichter, Phys. Rev. **101**, 58 (1956).

H2. de Haas-van Alphen Effect in Graphite. W. J. SPRY AND P. M. SCHERER, *National Carbon Company.*—The de Haas-van Alphen effect has been observed in single crystals of graphite using a pulsed magnet. This was a direct measurement of variation in the magnetic susceptibility as a function of magnetic field at the temperature of liquid helium. The main object of this report is to describe the manner in which a pulsed magnet can be used to observe relatively long-period oscillations at very low signal levels. The basic technique was that originally used by Schoenberg.[1] Measurements at magnetic fields as large as 100 kgauss did not indicate any new oscillations which were not extensions of those observed by Schoenberg,[2] and by Berlincourt and Steele,[3] at smaller fields with an electromagnet.

[1] D. Schoenberg, Physica **19**, 791 (1953).
[2] D. Schoenberg, Phil. Trans. Roy. Soc. (London) **245**, 1 (1952).
[3] T. Berlincourt and M. C. Steel, Phys. Rev. **98**, 956 (1955).

H3. On the Photoelectric Effect in Magnetic Metals. E. S. DAYHOFF, *U. S. Naval Ordnance Laboratory.*—The photoelectric emission current from magnetic metals under constant monochromatic illumination is known to change anomalously when the temperature is varied through the Curie point.[1] For nickel the emission is lowered by magnetic ordering whereas for iron the emission is raised. A theory of such phenomena has been given by Vonsovskii and Sokolov[2] in terms of basic parameters of the electronic energy band. Their principal assumption is that the band is of "free electron" type, parabolic upward (though of arbitrary effective mass), which is not a good assumption for nickel. These authors did not make a comparison of their theory with experimental results. As one may expect that some of the conclusions of the theory will still be valid for the parabolic downward bands of nickel, a qualitative discussion will be given of the relation of published experimental results to the theory, and a partial identification

of terms is made. An heuristic explanation of the difference in sign between the anomaly in iron and nickel will be given.

[1] See, e.g., A. B. Cardwell, Phys. Rev. **76**, 125 (1949); *ibid.*, Proc. Natl. Acad. Sci. U. S. **14**, 439 (1928).
[2] S. V. Vonsovskii and A. V. Sokolov, Doklady Akad Nauk S.S.S.R. **76**, 197 (1951).

H4. Magnetic Properties of the Mixed Garnets $(3-x)Y_2O_3 \cdot xGd_2O_3 \cdot 5Fe_2O_3$. ELMER E. ANDERSON, J. RICHARD CUNNINGHAM, JR., AND G. E. MCDUFFIE, *U. S. Naval Ordnance Laboratory.*—Polycrystalline garnets of the form $(3-x)Y_2O_3 \cdot xGd_2O_3 \cdot 5Fe_2O_3$ have been prepared for several values of x ranging from 0 to 3. Lattice constants vary linearly from 12.374 ± 0.005 A for yttrium-iron garnet ($x=0$) to 12.463 ± 0.005 A for gadolinium-iron garnet ($x=3$). Magnetic moments were measured from 77 to 580°K. For $x>0$ a dip in the magnetization curve appears at low temperatures. As x increases, this dip becomes more pronounced and occurs at higher temperatures, eventually becoming a compensation point at 300°K for $x=3$. The magnetic moments for the members of the series show reasonable agreement with values calculated on the basis of the Néel theory. Dielectric and permeability measurements were made on toroidal specimens having different values of x but the same relative density (~95%) and identical heat treatment. All samples have dielectric constants of ~13 from dc to 20 Mc/sec and electric loss tangents of ~0.004 at 20 Mc/sec. The permeability and magnetic losses have been measured from dc to 2000 Mc/sec in the temperature range from 77 to 300°K.

H5. Interactions and Distribution of Magnetic Ions in Some Garnet Systems. R. M. BOZORTH, S. GELLER, AND C. E. MILLER, *Bell Telephone Laboratories.*—The tetravalent ions of Si, Ge, and Sn have been incorporated into the garnet structure and their distribution and the interaction between the magnetic ions investigated. In the system $\frac{2}{3}(Y_3Fe_2Fe_3O_{12}) + \frac{1}{3}(Ca_3Fe_2M_3O_{12})$, M=Si, Ge, Sn, the saturation magnetization at 0°K indicates that Sn strongly prefers octahedral sites, Si tetrahedral sites. The finding for M=Si is corroborated in the system $\frac{2}{3}(Gd_3Fe_2Fe_3O_{12}) + \frac{1}{3}(Ca_3Fe_2Si_3O_{12})$. In the garnets $Ca_3Fe_2Ge_3O_{12}$ and $Mn_3Fe_2Ge_3O_{12}$ there are indications of antiferromagnetism: in the former the $1/\chi$ *vs* T curve becomes horizontal at low temperatures and in the latter there is a maximum in χ at about 6°K. In the compounds $Gd_3Co_2GaGe_2O_{12}$ and $Gd_3Ni_2GaGe_2O_{12}$ we observe only paramagnetism with a negative intercept of the $1/\chi$ *vs* T curve whereas $Gd_3Mn_2GaGe_2O_{12}$ has been found to be ferrimagnetic.[1] In comparison with the latter compound it was a surprise to find only a slight spontaneous magnetization, about 0.1β, in $Mn_3Fe_2Si_3O_{12}$ (kindly supplied by L. Coes of the Norton Company).

[1] M. A. Gilleo and S. Geller, J. Appl. Phys. **30**, 297S (Supp. to April, 1959).

H6. Magnetic Interactions and Ionic Distribution in the Garnet System: $Y_3Fe_2Fe_3O_{12}-Ca_3Fe_2Sn_3O_{12}$. S. GELLER, R. M. BOZORTH, M. A. GILLEO, AND C. E. MILLER, *Bell Telephone Laboratories.*—A complete solid solution range exists in the system $Y_3Fe_2Fe_3O_{12}-Ca_3Fe_2Sn_3O_{12}$. Because of its size, the Sn^{4+} ion prefers the octahedral positions; therefore, on small addition of the $Ca_3Fe_2Sn_3O_{12}$ (CIS) to YIG, the saturation magnetization at 0°K, σ_0, increases. A maximum of 7.3 μ_B per formula unit is reached at about 20 mole % solid solution of CIS in YIG. The moment, σ_0, then decreases to 5.2 μ_B at 33 mole % CIS and thereafter rapidly to 1.2 μ_B at 50 mole % CIS. At 67 mole % CIS, there are few Fe^{3+} ions in the octahedral sites and σ_0 is about 0.25 μ_B. One may explain the magnetic behavior of this system as follows: The magnetic interactions between the octahedral (a) and tetrahedral (d) Fe^{3+} ions in YIG are stronger than the a–a or d–d interactions. As more Sn^{4+} ions replace Fe^{3+} ions in the octahedral sites, σ_0 drops faster than would be expected from considering only the reduction of the number of magnetic interactions as a result of the substitution of nonmagnetic for magnetic ions. The weakening of the average a–d interaction as a result of addition of Sn^{4+} apparently results in the development of angles between, and ultimately, in the 67 mole % CIS case, to very nearly antiparallel ordering of, the moments of the tetrahedral ions. The behavior is perhaps analogous to that of the $MnFe_2O_4-ZnFe_2O_4$ system.

H7. Strong Absorption Bands of Compounds of Ferric Iron. A. M. CLOGSTON AND D. L. WOOD, *Bell Telephone Laboratories.*—Compounds of ferric ion and oxygen have strong untraviolet absorption bands whose origin is uncertain. The bands may arise from (a) the promotion of a $3d$ electron of the ferric ion into its own $4p$ shell or (b) they may involve the transfer of an electron from an oxygen ion to the ferric ion. This latter process has been called "charge transfer" but may also be recognized as an exciton process. If the ferric ion is surrounded by a symmetric octahedron of oxygen ions, theory indicates that there should be a difference in the absorption spectrum in the two cases. In case (a) neglecting spin orbit coupling, there should be two strong absorption lines corresponding to the free ion transitions $3d^5\ {}^6S \rightarrow 3d^4\,4p\ {}^6P^0$ and $3d^5\ {}^6S \rightarrow 3d^4\,4p\ {}^6F^0$, since ${}^6F^0$ will be strongly mixed with ${}^6P^0$ in the crystal field. In case (b) considerations of symmetry and of the various wave functions involved lead to a prediction of one strong and two weaker lines, plus a second similar group of much weaker absorptions at lower energy. The absorption spectrum expected for a ferric ion existing as an impurity in a host lattice will be similar to that expected for a concentrated crystal.

H8. Optical Absorption of Al_2O_3 Doped with Transition Metals. D. L. WOOD AND A. M. CLOGSTON, *Bell Telephone Laboratories.*—Absorption spectra have been measured up to 8 ev in a series of corundum (Al_2O_3) crystals doped with small percentages of various transition metal ions. One crystal containing iron was grown from flux by J. P. Remeika of Bell Telephone Laboratories, while others were obtained from the Linde Company and were grown by the flame fusion process. Measurements were made on a Cory Model 14 spectrophotometer and a Cario-Schmitt-Ott vacuum spectrograph. The spectra all show one or more discrete bands and an absorption edge, with different energies for bands and edge for the different dopings. The spectrum of Fe^{3+} in the flux grown crystal shows a single wide band at 4.8 ev similar to that found by Peria[1] at 4.3 ev for Fe^{3+} in MgO. The presence of trivalent iron in our crystal has been confirmed by paramagnetic resonance.[2] The spectra of all the crystals at 77°K were nearly identical to those at room temperature, with no additional structure resolved. It is felt that the measurements do not yet permit a decision between the two possible origins for the absorption bands mentioned in the previous abstract.

[1] W. T. Peria, Phys. Rev. **112**, 423 (1958).
[2] E. O. Shulz Dubois (private communication).

H9. Anomalous Magnetization and Approach to Absolute Saturation of Erbium Metal. WARREN E. HENRY, *U. S. Naval Research Laboratory.*—Investigations have been carried out on the magnetization of erbium metal to study the magnetic interaction and to determine the atomic magnetic constant, $g'J'$, so as to compare with the value, gJ, the spectroscopically determined product of the Landé splitting factor and the total magnetic quantum number. Values of the magnetization at 70 000 gauss are 0.5 Bohr magneton per atom of erbium at 295°K; 3.4 Bohr magnetons at 77.4°K and 6.6 Bohr magnetons at 4.2°K and 1.3°K. At 77.4°K there is an easily detectable remanence (2×10^{-4} Bohr magneton per atom). The remanence is 0.5 Bohr magneton per atom at 4.2°K and 0.8 Bohr magneton at 1.3°K. This ferromagnetism at liquid helium temperatures accords nicely with the neutron diffraction studies of Koehler

which indicated ferromagnetic scattering at these temperatures. The value of 6.6 Bohr magnetons per atom of erbium is less than the 9.6 predicted by simple theory for the $^4I_{15/2}$ state and the 10-Bohr magnetons inferred from low-field high-temperature susceptibility measurements. This low saturation magnetization is similar to some other rare earth metals (neodymium, dysprosium, terbium, and holmium) studied at NRL and may result from the combined effect of the crystalline electric field and spin-orbit interactions.

H10. Conductivity and Polarizability Tensors of Ferromagnetic Crystals.* JACK C. MILLER, *Pomona College.*—The work of Argyres[1] has prompted a theoretical study of the conductivity and polarizability tensors in ferromagnetic crystal structures, which is valid to the second order in a standard perturbation theory approach, when the perturbation is plane electromagnetic radiation. In order to retain a certain measure of generality, the results of Argyres are recast in a form which brings out the properties of the particular crystal group under consideration. The appropriate terms for the Kerr, Faraday, and Cotton-Mouton effects are written in a form which involves the representation of the given crystal group. Some of these are evaluated for the cubic group (Oxi) using the well-known properties of group representations. The results enable calculation of transmission and reflection effects from ferromagnetic substances using a space averaged form of the total current within a ferromagnetic material. The question of the gauge invariance of the theory is discussed.

* Supported by the Office of Naval Research.
[1] P. N. Argyres, thesis, University of California, Berkeley; and Phys. Rev. **97**, 334 (1955).

H11. Neutron Diffraction Investigations of the Magnetic Ordering in CrF_2 and $CrCl_2$. J. W. CABLE, M. K. WILKINSON, AND E. O. WOLLAN, *Oak Ridge National Laboratory.*—Neutron diffraction investigations have been performed on CrF_2 and $CrCl_2$ to determine the existence of magnetic ordering in these compounds at low temperatures. Although the chemical unit cells of these compounds are monoclinic and orthorhombic, respectively, both structures are distortions of the rutile structure and are consequently similar to MnF_2, FeF_2, CoF_2, and NiF_2 which have been investigated previously at this laboratory.[1] Antiferromagnetic reflections were observed from polycrystalline CrF_2 below about 50°K, and these reflections can be indexed on the basis of a magnetic unit cell which has the same dimensions as the chemical unit cell. The magnetic structure appears to be identical to those of the other iron-group difluorides in which the atomic moments at the lattice corners are antiparallel to those at the center of the unit cell. In $CrCl_2$, an antiferromagnetic transition is observed at about 20°K, and the magnetic structure is different from those of the difluorides. The antiferromagnetic reflections require a magnetic unit cell in which the b axis and c axis are twice those of the chemical cell, but the a axis is the same as that of the chemical cell. The suggested magnetic structure has ferromagnetic (011) planes with adjacent planes antiparallel.

[1] R. A. Erickson, Phys. Rev. **90**, 779 (1953).

H12. Antiferromagnetism in MoF_3. M. K. WILKINSON, E. O. WOLLAN, AND H. R. CHILD, *Oak Ridge National Laboratory.*—Neutron diffraction investigations on a compound of molybdenum fluoride have shown the existence of antiferromagnetic ordering in this material at low temperatures and should provide interesting information on the magnetic behavior of ions in the 4*d* transition series. This compound, which has been analyzed chemically to be MoF_3, has a bimolecular rhombohedral unit cell very similar in dimensions to those which exist in trifluoride compounds.[1] The molybdenum ions form hexagonal layers which are perpendicular to the unique axis of the crystal, and fluorine ions are located between these layers. Antiferromagnetic reflections are observed in the neutron diffraction patterns at low temperatures and the disappearance of these reflections gives a Néel temperature of 185°K. The magnetic reflections indicate an antiferromagnetic structure in which the atomic magnetic moments are aligned parallel within each hexagonal layer and the moments of adjacent layers are antiparallel. In this type of magnetic structure, each metal atom is antiferromagnetically coupled to all of its six nearest neighbors.

[1] Hepworth, Jack, Peacock, and Westland, Acta. Cryst. **10**, 63 (1957).

H13. Exact Treatment of the Antiferromagnetic Ground State.* H. L. DAVIS AND JAN KORRINGA, *The Ohio State University.*—For the purposes of this paper an antiferromagnet is defined by the Hamiltonian,

$$H=2|J|\Sigma_{(\text{neighbors})}\{S_i^z S_k^z+(1-\alpha)[S_i^x S_k^x+S_i^y S_k^y]\},$$

where α is an anisotropy parameter. The ground-state wave function of this Hamiltonian is obtained in terms of a linked-spin-cluster expansion, similar to Goldstone's[1] linked-Feynman-diagram expansion, which gives, in principle, an exact solution of this magnetic many-body problem. The ground-state energy, short-range order, and long-range order are given for 1-, 2-, and 3-dimensional spin arrays and compared with the corresponding quantities calculated by variational means.[2,3] A discussion is given, for both ground-state and excited state problems, of the applicability of the linked-spin-cluster method to Hamiltonians other than the one used here.

* Assisted by U. S. Air Force Office of Scientific Research.
[1] J. Goldstone, Proc. Roy. Soc. (London) **A239**, 267 (1957).
[2] P. W. Kasteleijn, Physica **18**, 104 (1952).
[3] H. Taketa and T. Nakamura, J. Phys. Soc. Japan **11**, 919 (1956).

H14. Dielectric Constant of $BaTiO_3$ Single Crystals from 1 kc to 2500 Mc.* A. LURIO AND E. STERN, *IBM Watson Laboratory.*—Measurements were made on single crystals of $BaTiO_3$ in order to observe the dielectric constant and the losses as a function of frequency. The range of observation was from 1 kc to 2500 Mc; at each frequency the temperature was varied from room temperature to 160°C. The sample, 1×1×0.2 mm, was placed at the end of a coaxial line between the center conductor and a spring-loaded short-circuit. The crystal edges in contact with the line were electroded with evaporated gold. This arrangement was used throughout the measuring range. In this configuration the sample can be visualized as equivalent to a two-terminal network of lumped circuit elements. The measurements yield only the input admittance as a function of temperature at the various frequencies. This allows any number of interpretations of the network in terms of its resistive and reactive components. The data were analyzed on the basis of two different equivalent circuits, namely a parallel RC network and a series RC network. It is found that in the series model, the dielectric constant does not change appreciably from 1 kc to 2500 Mc. The results will be discussed in the light of both of these models.

* This research was done under Bureau of Ships Contract.

H15. Symmetry of $BaTiO_3$ below −80°C.* ETSURO SAWAGUCHI,† *Rutgers, The State University of New Jersey.*—Kay and Vousden[1] suggested that the crystal symmetry of $BaTiO_3$ below −80°C is rhombohedral. Devonshire's theory[2] has since supported this suggestion. Recently, Jona and Pepinsky[3] suggested a lower symmetry, such as monoclinic, in order to explain several anomalous properties of $BaTiO_3$ observed at low temperature. An attempt has been made, by optical means, to find the crystal symmetry. Very small (111) plates were prepared from $BaTiO_3$ single crystals and the

domain structure was examined under a polarizing microscope. Optically, four kinds of domains exist below −80°C; one of which shows total extinction and strongly suggests that the crystal is optically uniaxial. Unless the direction of the spontaneous polarization is parallel or nearly parallel to the (111) direction, it is very difficult to explain the observed optical properties. Thus, it is highly probable that the $BaTiO_3$ has rhombohedral symmetry.

* Supported in part by Rome Air Development Center, U. S. Air Force.
† On leave of absence from the Electrotechnical Laboratory, Tokyo.
[1] H. F. Kay and P. Vousden, Phil. Mag. **40**, 1019 (1949).
[2] A. F. Devonshire, Phil. Mag. **40**, 1040 (1949).
[3] F. Jona and R. Pepinsky, Phys. Rev. **105**, 861 (1957).

THURSDAY AFTERNOON AT 2:00

Room B in Departmental Auditorium

(K. A. BRUECKNER presiding)

Theory, II: Statistical

HA1. Particle Concept. JOSEPH G. BARREDO, *C.S.I.C.*—A particle concept is given in which all observable particle properties are a function of its internal coordinates (*meta*-coordinates). This is done through a submicroscopic revision of the three consistent classes of quantities introduced macroscopically by the three founders of mathematical analysis: (1) coordinates, the core of Descartes analytical geometry; (2) fluents, the central concept of Newton's analytical mechanics; and (3) functions, introduced by Leibnitz, which play a paramount role in pure analysis. The conclusions cannot be more valid than the concepts, however correct the equations relating them may be. Therefore, a submicroscopic revision of the coordinate concept, which is the core of concepts (2) and (3) above, is necessary in order to demonstrate: (1) Yukawa's suggestion[1] that the rigid framework of the theory of relativity and quantum mechanics could not remain without modification in the future theory of particles. (2) That the framework rigidity comes not only from both theories but also from the electrodynamics in which both are based, as triondynamics[2] shows. (3) That Einstein's desire for a deterministic explanation of physical phenomena can be fulfilled by abandoning Einstein's space-time concept.

[1] H. Yukawa, Prog. Theort. Phys. **16**, 688 (1956).
[2] J. G. Barredo, Naturwissenschaften **15**, 346 (1956); *ibid.*, Bull. Am. Phys. Soc. Ser. II, **3**, 369 (1958).

HA2. New Expansion Theorem for Radiated Fields.* S. KARP AND N. ZITRON, *New York University and Harvard University.*—Let A be a fixed region of arbitrary size, and let d be the distance from a point in A to the center of a circle containing all the sources or singularities of a radiated (or reradiated) field u. Then at points in A, the function u can be expanded in a series of inverse powers of d. The coefficients are expressible as finite linear combinations of a plane wave and its derivatives with respect to angle of incidence. We give the entire series explicitly, in the case of two dimensions. The result is useful in reducing multiple scattering problems to the problem of single scattering of a plane wave.

* The research reported in this paper has been sponsored in part by the Electronics Research Directorate of the Air Force Cambridge Research Center, Air Research and Development Command, and in part by the Office of Naval Research.

HA3. Scattering Lengths for Compound Systems. LEONARD ROSENBERG AND LARRY SPRUCH, *New York University.*—In the zero energy scattering of a particle by a compound system, the Kohn variational principle is shown to provide an upper bound on the scattering length $\bar{A}$ if the particle and the scattering system cannot form a composite bound state. As a first example, the scattering of positrons by hydrogen is studied. We find $\bar{A} < -1.40a_0$. Since $\bar{A}$ would be positive if the hydrogen atom were unperturbed in the scattering process it is seen that polarization has a major effect. The trial function was determined with the aid of the rigorous criterion that the best result is the one giving the smallest scattering length. This criterion may be used to reanalyze many previous variational calculations. Thus, recent neutron-deutron quartet scattering calculations by Sartori and Rubinow are restudied. For the ordinary (WB) force mixture, with no polarization, a 17% improvement is obtained by converting the variational principle used to the Kohn form using their unpublished values of the necessary integrals. With the above criterion the best trial function constructed by Sartori and Rubinow with polarization yields $A_s < 4.8$ fermis for the ordinary force mixture (private communication), a 30% improvement over their published result.

HA4. Perturbation Theory of the Nuclear Many-Body Problem. J. S. LEVINGER, M. RAZAVY, AND O. ROJO, *Louisiana State University.*—Following Tobocman,[1] we modify perturbation theory for application to a two-nucleon potential consisting of a hard core and an attractive potential. The expansion for the nuclear binding energy gives a series in powers of the core radius, and in powers of the strength of the attractive potential. Individual terms in the series are evaluated using Euler's techniques.[2] The rapidity of convergence of the series is being investigated for different choices of the two-nucleon potential.

[1] W. Tobocman, Phys. Rev. **107**, 203 (1957).
[2] H. Euler, Z. Physik **105**, 553 (1937).

HA5. Brownian Particles in a Nonuniform Fluid.* J. L. LEBOWITZ, *Stevens Institute of Technology.*—The time evolution of the distribution fucntion for a Brownian particle in a fluid is described by the Fokker-Planck equation. When the temperature of the fluid is uniform this equation leads to the Brownian particle achieving a Maxwell-Boltzmann distribution asymptotically in time. We have now found the stationary distribution of the Brownian particles for the case when the temperature and pressure of the fluid are not uniform, to terms linear in the gradients. We can also show that this solution is approached asymptotically in time.

* Supported by the Air Force Office of Scientific Research.

HA6. Statistical Mechanics of Real Fluids. HOWARD REISS AND H. L. FRISCH, *Bell Telephone Laboratories*, AND J. L. LEBOWITZ, *Stevens Institute of Technology.**—The techniques applied by the authors to rigid spheres[1] have been extended to the treatment of certain real substances (Ne, A, He, H_2, N_2, O_2, Cl_2, C_6H_6, and solutions of these) with good results. We have been able to calculate the surface tensions of these substances as well as the Henry's law constants for certain solutions of them. In addition the equations of state

of the more simple fluids can be derived and compare well with experiment.

* Supported by the U. S. Air Force Office of Scientific Research.
[1] Reiss, Frisch, and Lebowitz, Bull. Am. Phys. Soc. Ser. II, 4, 15 (1959).

HA7. Evaluation of Collision Integrals, Using Grad's Representation of the Distribution Function.* E. IKENBERRY, *Alabama Polytechnic Institute.*—Grad's[1] Hermite polynomials $H^{(n)}(\mathbf{x})$ in $\mathbf{x}=x_1, x_2, x_3$ and the corresponding completely symmetric tensors $\mathbf{H}^{(n)}(\mathbf{x})$ of order n may be defined by the generating function $\exp(-\frac{1}{2}\mathbf{r}^2+\mathbf{r}\cdot\mathbf{x})$. Explicit evaluation of all collision terms $J^{(n)}$ in terms of the Hermite coefficients $a^{(n)}$ is equivalent to conversion of a certain definite integral $R(\mathbf{p},\mathbf{q},\mathbf{r})$ into a power series in $\mathbf{p}$, $\mathbf{q}$, and $\mathbf{r}$. Explicit expressions for the coefficients in the series are given, for any spherically symmetric molecular model. Simplified expressions for the coefficients in the series are obtained for rigid elastic spheres and for inverse power molecules, in particular, for Maxwellian molecules.

* E. Ikenberry, Arch. Rational Mech. (to be published).
[1] H. Grad, Commun. on Pure and Appl. Math. 2, 331–407 (1949).

HA8. Evaluation of the Pair Distribution Function for a Hard Sphere Bose Gas.* LEOPOLDO COLIN SCHERER† AND JEAN PERETTI, *University of Maryland.*—The pair distribution function for a quantum system is expressed as a power series of the fugacity, the coefficients of which are temperature dependent. For the hard sphere case these coefficients have been calculated to the first order in a/λ (where a is the scattering length of the interacting potential and λ the thermal wavelength) using torons with two fixed points (cf. Montroll and Ward[1]) or alternatively U functions (cf. Huang *et al.*[2]).

* Work supported by the U. S. Air Force.
† On leave from Instituto Nac. de la Investigación Científica, México.
[1] E. W. Montroll and J. C. Ward, Phys. Fluids 1, 55 (1958).
[2] Huang, Lee, and Yang, Stevens Conference on Many Body Problems (1957) and "Binary collision method in quantum statistical mechanics" (to be published).

HA9. Modified Interaction and Pair Distribution Function in Quantum Statistical System.* S. FUJITA AND R. HIROTA, *Northwestern University.*—A simpler formulation of Montroll-Ward theory[1] is proposed by using standard field-theoretic approach. Assuming the general simple chain approximation it is shown that quanta transmitted between particles are identified as plasmons and phonons, for the cases of electron gas and hard-sphere quantum gases, respectively, at low temperatures. This will be discussed with the calculation of pair distribution functions based on the general formalism developed by Fujita *et al.*[2]

* Work supported by the Office of Naval Research and the National Science Foundation.
[1] E. W. Montroll and J. C. Ward, Phys. Fluids 1, 55 (1958).
[2] Fujita, Isihara, and Montroll, Bull. Am. Phys. Soc. Ser. II, 4, 14 (1959).

HA10. Stochastic Equations for Relaxation Processes. DAVID FALKOFF,* *Harvard University.*—We consider a system of Maxwell-Boltzmann particles (atoms or spins) interacting with a system of bosons (photons or phonons). Each system is described by the *probability distribution* of the occupation numbers of its independent particle states. The "master" equation for the time rate of change in these joint distributions is obtained from the quantum mechanical transition probabilities for emission or absorption of a boson by the Maxwell-Boltzmann particles. This has been solved to obtain the probability distribution for all time describing the relaxation of either system when the average populations of the other are fixed. From this probability distribution one gets not only the usual relaxation equations for the average populations, but also all moments and fluctuations as well. This makes it possible to give an operational meaning to the concept of temperature for an anomalously excited degree of freedom in terms of the measurable fluctuations in occupation numbers even when the system as a whole is not in thermal equilibrium.

* National Science Foundation Senior Postdoctoral Fellow on leave from Brandeis University.

HA11. On the Validity of the Collision Term Expansion in a Taylor Series for Hot Electron Theory. I. ADAWI, *RCA Laboratories.*—The Boltzmann equation for a nondegenerate, quasi-free electron gas in a strong electric field is considered with a general electron-phonon interaction. The necessary and sufficient conditions under which the collision term can be reduced to a differential operator are given. A Debye and an Einstein model are assumed for the acoustical and optical phonons, respectively. It is shown that, in addition to the customary expansion parameter being less than unity, the basic criterion is that the logarithmic derivative of the distribution function changes little over an energy interval equal to the phonon energy. This is satisfied for all fields if the phonon distribution can be described classically ($\hbar\omega \ll KT$). Otherwise, the simplified condition is $(qE\tau)^2 \gg (mc)^2$ for acoustical phonons, and $(qEl)^2 \gg (\hbar\omega_0)^2$ for optical phonons, where q and m are the electron charge and effective mass respectively, E is the electric field, τ is of the order of the relaxation time, c the speed of sound, l the mean free path, and $\hbar\omega_0$ is the characteristic optical phonon energy. It is proved that when the field is set equal to zero in the final results the Maxwellian distribution is restored if, and only if, equipartition is valid for the lattice oscillators. The above results will rectify some of the misleading statements encountered in the literature.

HA12. Variational Principle for Stationary Irreversible Processes.* PETER G. BERGMANN, *Syracuse University.*—If a system which internally obeys the laws of classical mechanics is exposed to continuing contact with several inexhaustible reservoirs, its Gibbsian distribution in phase space will tend asymptotically to a stationary distribution, which is independent of the initial distribution and which will not be canonical if the driving reservoirs are at different temperatures.[1] It will be shown that the quantity $K=\int \mu^{-1}\dot{\mu}^2 dX$, which is positive definite, decreases monotonically in the course of time and approaches zero asymptotically. Accordingly, it is suggested that K is a natural expression for the determination of how close a given distribution is to the stationary distribution, and that it may be suitable for the construction of approximation procedures leading to the stationary distribution.

* Supported by the U. S. Air Force Office of Scientific Research.
[1] J. L. Lebowitz and P. G. Bergmann, Ann. phys. 1, 1 (1957).

HA13. Transport Coefficients from Fluctuation Dissipation in the Canonical Ensemble. EUGENE HELFAND, *Bell Telephone Laboratories.*—Expressions for the self-diffusion coefficient and the bulk and shear viscosities are obtained by studying the regression of fluctuations in a canonical ensemble. The method consists of observing at time $t=0$ the position and momentum of an arbitrary molecule in each of the systems of an equilibrium ensemble. The ensemble is then divided according to the results of this measurement. Rigorous distribution functions for each of these nonequilibrium subensembles can be written. One then calculates, both hydrodynamically and statistical mechanically, an appropriately weighted average of the spread of the initial knowledge with time. Equating the rwo results yields statistical expressions for the transport coefficients. The Einstein equation is obtained for the self-diffusion coefficient and similar formulas for the others. Energy correlations cause difficulties in applying the method to thermal conductivity, but the calculation can be made if these correlations are neglected. The results of this work can be recast into the form of expressions given by M. S. Green, Mori, and Kubo.

FRIDAY MORNING AT 9:30

Willard, Congressional Room

(V. L. SAILOR presiding)

Neutron Interactions with Solids and Liquids; Neutron Capture

J1. Performance of a Low-Pass Neutron Filter.* H. BJERRUM MOLLER AND F. J. SHORE, *Brookhaven National Laboratory.*—A neutron filter, dependent on thermal diffuse scattering as suggested by Brockhouse, has been tested for the purpose of minimizing second-order neutrons in a crystal spectrometer. The filter consists of large single crystals of quartz which have a neutron cross section increasing with energy in a region around 0.1 ev. It was found to be useful for pile neutrons in the energy region from 0.02 ev to 0.10 ev where in an unfiltered spectrometer beam the second-order contamination is particularly large. The transmission of the first-order neutrons decreased from about 25% at 0.02 ev to 1% at 0.1 ev for 12-in. quartz. The second-order contamination was reduced by a factor ranging between 12 and 23. At both the lower and higher energy extremes the reduction factor became smaller. At higher energies the transmitted flux was reduced to below 1%, and the background became unfavorable. The measured properties agree with calculations based on published neutron cross-section data which we have verified. Results will be discussed for NaCl(200) and Be($10\bar{1}1$) planes. Cooling the filter to liquid nitrogen temperature, which should decrease the thermal diffuse scattering, increases the measured transmission. A filter such as this, which discriminates strongly against neutrons of energy greater than 0.1 ev, should find many uses around a pile.

* Work supported by the U. S. Atomic Energy Commission.

J2. Monoenergetic Neutron Beams in the Thermal Range from a Germanium Monochromator and Quartz Filter.* B. M. RUSTAD, J. T. WAJIMA, AND E. MELKONIAN, *Columbia University and Brookhaven National Laboratory.*—A study was made of the higher order contamination in the Bragg reflection of a neutron beam from the (111) plane of a germanium single crystal. Germanium has a diamond cubic structure; the second-order (222) reflection is forbidden. McReynolds has suggested that crystals of this type should prove useful for producing nearly monoenergetic beams at energies below the peak of a reactor spectrum (~0.08 ev). Calculations of the intensity ratios of third- and fourth-, to first-order neutrons at thermal energy when detected with a 1/v, BF_3 counter yield $I_3/I_1=0.0245$ and $I_4/I_1=0.0055$, respectively. The order contamination determined experimentally with a second, silicon crystal analyzer is $I_3/I_1=0.023\pm0.002$ in agreement with the predicted value. A maximum value of 0.2% was also measured for the second-order reflection. The total higher order contamination, determined from the transmission of a gadolinium sample, is less than 4.6%. A quartz filter (suggested by Brockhouse), composed of six 2-in. single crystals, was used further to reduce order contamination. At thermal energy, the order contamination measured in the filtered beam is $I_2/I_1=3.7\pm0.7\times10^{-4}$ and $I_2/I_1\leq2.1\times10^{-4}$ to be compared with the values $3.2\pm0.3\times10^{-4}$ and 1.8×10^{-4}, respectively, computed from the known transmission of the quartz filter.

* This work was partially supported by the U. S. Atomic Energy Commission.

J3. Mechanical Neutron Filter for Subthermal Neutrons.* J. A. MOORE, J. RUSH, AND B. M. RUSTAD, *Columbia University and Brookhaven National Laboratory.*—The neutron velocity selector,[1] which was designed to be used as a continuously variable neutron filter to remove second- and higher order neutrons from the beam of the Columbia crystal spectrometer for wavelengths above 8 A, has been improved to filter all wavelengths greater than 1 A, corresponding to the peak of the neutron spectrum of the Brookhaven reactor. The velocity selector consists of a rotor, containing helical slots, driven at variable speed. The angle between the axis of the rotor and the direction of the neutrons can be varied to change continuously the effective pitch of the helical slots. The extension in wavelength achieved by this motion would require a factor of 4 increase in the maximum design value of the rotor velocity, which is presently 6500 rpm. From 1 A to 3.5 A, the spectrometer monochromator is a germanium crystal [(111) plane for which the second-order reflection is forbidden]. A mica crystal, which has a larger crystal plane spacing, is used for the monochromator from 3.5 A to 12 A. The higher order contamination in the beam after the filter is less than 0.5% over the entire wavelength range.

* This work was partially supported by the U. S. Atomic Energy Commission.

[1] N. Holt, Rev. Sci. Instr. **28**, 1 (1957).

J4. Competitive Extinction in Neutron Monochromating Crystals.* R. R. SPENCER AND J. R. SMITH, *Phillips Petroleum Company, Idaho Falls.*—Large anomalies have been observed in the Bragg beam produced by Be($10\bar{1}1$) and Be($10\bar{1}3$) monochromators on the MTR crystal spectrometer. Instead of a smooth spectrum characteristic of a Maxwellian distribution of neutron velocities, many large dips were found. These dips appear to be caused by extinction of the beam due to Bragg reflection by planes in the crystal other than those supplying the Bragg beam to the spectrometer. Calculations of the angles at which such competition can be expected have resulted in the identification of the planes responsible for the principal dips. To establish that these anomalies are due to crystal properties, spectra produced by the (200), (220), and (240) planes of NaCl were also examined. Although a few extinction dips were observed, these were far smaller in number and amplitude than those found in Be, due to the simpler crystal structure and lower reflectivity of NaCl. These effects require careful consideration in high-accuracy experiments with the crystal spectrometer, particularly in the measurements of reactor spectra.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

J5. Analysis of Inelastic Neutron Scattering from Liquid Helium. MICHAEL COHEN, *University of Pennsylvania* (introduced by J. M. Luttinger).—The energy *versus* momentum relation for the elementary excitations in liquid helium has recently been measured by means of inelastic scattering of cold neutrons.[1-3] The temperature-dependent line shift and width indicate that the excitations interact. One would like to extract information about the interaction from the line form, and also to find the optimal recipe connecting the scattering data with the specific heat. A model has been analyzed in which the liquid is represented as a collection of excitations, all with energy greater than a minimum value Δ, with the pairwise interaction $\Sigma\langle kl|v|ij\rangle a_k^* a_l^* a_i a_j$. The line shape and specific heat are calculated as power series in the excitation density $\exp(-\Delta/kT)$, the coefficients being correct to all orders in the interaction v. A Lorentzian form is obtained at

low temperatures; diagrammatic representation shows that the line shift and specific heat are simply related in low orders of $\exp(-\Delta/kT)$. The Los Alamos recipe[4] is correct in the first two orders. Higher order corrections will be discussed.

[1] Palevsky, Otnes, and Larsson, Phys. Rev. 112, 11 (1958).
[2] Yarnell, Arnold, Bendt, and Kerr, Phys. Rev. Letters 1, 9. (1958).
[3] D. G. Henshaw, Phys. Rev. Letters 1, 127 (1958).
[4] Bendt, Cowan, and Yarnell, Phys. Rev. (to be published).

J6. Lattice Vibrations in Silicon by Scattering of Cold Neutrons. W. KLEY, *University of Freiburg*, E. TUNKELO, *Finland Institute of Technology*, D. J. HUGHES AND H. PALEVSKY, *Brookhaven National Laboratory*.—Upon absorption of a phonon while scattering, a cold neutron changes energy by such a large amount that the phonon energy can usually be fixed accurately. The method is particularly useful for the optical vibrations, as shown by the first measurements of high-frequency modes in zirconium hydride and germanium, cases for which infrared work had given inconclusive results. In the light of similar uncertainty concerning the optical (Raman) frequency in silicon, we have determined it, as well as one acoustical branch, by use of cold neutron scattering. In the present measurements, the incident neutron beam was perpendicular to the (100) plane of the silicon single crystal. The energy of neutrons scattered at 90° was determined by measuring their time of flight over a 5-m flight path, utilizing a slow chopper. Points for $\mathbf{q}$ in the [110] direction, extrapolated to $\mathbf{q}=0$, give the energy of the Raman line as 0.063 ± 0.003 ev (phonon frequency ν of 15.2×10^{12} cps), and at the edge of the Brillouin Zone (maximum $\mathbf{q}$) in the [110] direction the transverse acoustic branch has an energy of 0.020 ± 0.002 ev ($\nu=4.84\times10^{12}$ cps). In first approximation the vibration frequencies of Si and Ge should be inversely proportional to the square root of the masses of the vibrating atoms. This ratio is 1.61 and a comparison of our Si and Ge data gives ratios of 1.69 ± 0.1 (optical) and 1.61 ± 0.15 (acoustical).

J7. Lattice Vibrations in NaI from Neutron Spectrometry. A. D. B. WOODS, W. COCHRAN, AND B. N. BROCKHOUSE, *Chalk River Laboratory*.—The frequency-wave vector relation of the normal modes propagating in the symmetric [100], [111], and [110] directions in a single crystal of sodium iodide at 100°K, are being measured by neutron spectrometry using the method of successive approximations.[1] Inelastic structure factors computed on the Born model of an ionic crystal using the Coulomb lattice sums of Kellermann have been used to guide the experiments. To data the transverse acoustic (TA), longitudinal acoustic (LA), and transverse optic branches have been determined. It is hoped to extend the measurements to the longitudinal optic branch. The transverse optic branch is everywhere almost flat with frequencies up to 10% higher than the reststrahlen frequency of $3.7(\pm0.1)\times10^{12}$ cps measured in this experiment. Other frequencies (units 10^{12} cps) are TA (100) 1.22 ± 0.04, TA ($\frac{1}{2},\frac{1}{2},\frac{1}{2}$) 1.50 ± 0.07, LA (100) 1.82 ± 0.06. The results show significant disagreements with the Born-Kellermann model. So far the results agree with calculations on another model in which the polarizabilities of the ions are taken into account by dividing each ion into a core and a spherical shell which have the same equilibrium positions (but not instantaneous positions) and which interact with each other and with the cores and shells of their nearest neighbors.

[1] B. N. Brockhouse and P. K. Iyengar, Phys. Rev. 111, 747 (1958).

J8. A Neutron Time-of-Flight Study of the Einstein Energy for Several Metal Hydrides.* W. L. WHITTEMORE AND A. W. MCREYNOLDS, *General Atomic*,† AND I. PELAH, *Weizmann Institute of Science, Rehovoth*.—A study of the inelastic scattering of neutrons by zirconium hydride has yielded much information on the binding of hydrogen in this metal hydride.[1,2] A similar technique, using in place of "cold" neutrons a monoenergetic beam of neutrons with energy 0.0685 ev, has been used to measure the Einstein energies of the "optical" levels for LiH, MgH_2, TiH_2, $ZrH_{1.6}$, and YH_2. The relation between the length of the hydrogen bond and the Einstein energy will be discussed. In addition, a comparison of the "optical" frequency determined for LiH in this experiment will be made with that determined from the Debye characteristic temperatures of LiH and LiD.[3]

* Performed at Brookhaven National Laboratory under the auspices of the U. S. Atomic Energy Commission.
† John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.
[1] I. Pelah *et al.*, Phys. Rev. 108, 1091 (1957).
[2] A. Andresen *et al.*, Phys. Rev. 108, 1092 (1957).
[3] C. K. Stanbaugh and R. M. Harris, Phys. Rev. 86, 651(A) (1952).

J9. Slow Neutron Scattering by Hydrogen.* A. W. MCREYNOLDS AND W. L. WHITTEMORE, *General Atomic*.†—Our high-current electron linac has been used as a pulsed source for neutron spectrometry studies of the effect of chemical binding on hydrogen scattering. The initial fission spectrum pulse was first partly thermalized in a hydrogenous moderator adjacent to the target. As the moderator temperature is decreased through the range from 300°K to 4°K, the neutron spectrum in the pulse shifts to lower energies, greatly enhancing the cold neutron intensity, although the deviation of observed from equilibrium Maxwellian spectrum is greatest at low temperatures because of decreased phonon population. By time-of-flight transmission measurements, the total scattering cross sections have been compared for H in liquid and solid H_2O, polyethylene, and H_2 gas, over the energy range 0.001 ev to 0.4 ev of transition from free to bound states. Results are interpreted in terms of binding and related to previously measured inelastic scattering properties.

* This work was supported in part by the U. S. Atomic Energy Commission.
† John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.

J10. Compton Spectrometer for Neutron Capture Gamma Rays. H. T. MOTZ, R. E. CARTER, AND P. C. FISHER, *Los Alamos Scientific Laboratory*.*—A $\sqrt{2}\pi$ double-focusing beta-ray spectrometer with a mean radius of 34 cm is being used to analyze the Compton electrons originating in a beryllium converter from gamma rays produced by neutron capture. Sources are located in the thermal column of the Omega West Reactor and a collimated gamma-ray beam is brought through the reactor shield tangential to the mean orbit of the spectrometer. The spectrometer has four curved slits in the focal plane to allow the use of four plastic scintillation detectors. A NaI detector near the converter and outside of the primary beam is used to record scattered gamma-electron coincidences. When the angle of these back-scattered gamma rays is properly defined, the coincidence line shape exhibits improved resolution over the electron singles line shape.[1] Coincidence data from 0.5 to 6.5 Mev have been observed with line widths of 1.0 and 0.5% resolution from 3 cm^3 converters of 3.4 and 12.4 mg/cm^3, respectively. Preliminary data obtained with this instrument will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] H. T. Motz, Phys. Rev. 104, 1353 (1956).

J11. Gamma Radiation following Thermal Neutron Capture in Gd^{157}. J. W. KNOWLES, G. A. BARTHOLOMEW, AND P. J. CAMPION, *Atomic Energy of Canada Ltd.*—The γ rays of Gd^{158} following neutron capture in the separated isotope Gd^{157}, have been studied from 0.78 to 3.0 Mev with a flat crystal diffraction spectrometer, resolution about 0.5%, and from 3.0 to 8.2 Mev with a pair spectrometer, resolution 1.0%. More than 100 gamma rays have been resolved and these account for about 50% of the total energy radiated per capture. The remaining

radiation is accounted for by the unresolved continuum. On the basis of a proposed decay scheme the binding energy of Gd^{158} is 7.854±0.008 Mev in agreement with mass measurements.[1] Measured low-energy γ rays at 79.56±0.03, 182.3 ±0.2, 277.0±0.1, and 359.3±0.4 kev can be interpreted as transitions in the $K=0$ ground-state rotational band with levels at 79.56 (2+), 261.9 (4+), 538.9 (6+), and 898.2 (8+) kev. Values of the moment of inertia parameter $\hbar^2/2I=13.33$ kev and the rotation-vibration parameter $B=0.0120$ kev, calculated from the levels at 79.56 and 261.9 kev, predict 6+ and 8+ levels at 538.9 and 898.0 kev in agreement with the experimental values.

[1] W. H. Johnson, Jr., and V. B. Bhanot, Phys. Rev. **107**, 1669 (1957).

J12. Gamma Radiation following Thermal Neutron Capture in Natural Neodymium. P. J. CAMPION, J. W. KNOWLES, AND G. A. BARTHOLOMEW, *Atomic Energy of Canada Ltd.*—The gamma rays following thermal neutron capture in neodymnium have been studied from 0.3 to 2.75 Mev with about 0.5% resolution using a crystal diffraction spectrometer and from 3.3 to 8.5 Mev with 1.0% resolution using a pair spectrometer. Some 80 gamma rays have been resolved and a tentative decay scheme for the more intense radiations in Nd^{146} has been made (Nd^{143} contributes about 76% of the total capture cross section). The decay scheme has been confirmed in part by coincidence measurements using NaI (Tl) scintillation spectrometers. The binding energy of Nd^{144} is found to be 7.814±0.008 Mev, in agreement with mass measurements.[1] The energies of some of the lower levels in this nucleus are 0.696±0.001, 1.313±0.001, and 1.556±0.008 Mev. Since the ground state of Nd^{143} is $\frac{7}{2}-$, the capturing state in Nd^{144} is 3− or 4−. Assuming that one resonance only contributes appreciably to capture[2] the observation, in the present experiment, of a relatively strong primary transition to the 2+, 0.696-Mev level suggests that the resonance is 3−.

[1] W. H. Johnson, Jr., and A. O. Nier, Phys. Rev. **105**, 1014 (1957).
[2] H. J. Hay, J. Nuclear Energy **7**, 199 (1958).

J13. Possibility of Anomalous Abundance Ratios of Elements Produced by Rapid Neutron Capture in Supernovae. ROBERT A. BECKER, *University of Illinois.*—On a rapid neutron-capture path isobaric abundances are inversely proportional to $(Z-Z_A)^5$ where Z is the charge of the neutron-rich nucleus and Z_A is that of the hypothetical most-stable nucleus having the same atomic weight A. On shell closure at 50, 82, and 126 neutrons the capture path approaches several units of Z more closely to the stability line, thus resulting in abundance peaks at these points. A given path is determined by a choice of Q_n, n_n, and T, respectively, the critical neutron binding energy, density of neutrons, and temperature. For different choices of these quantities it is possible to obtain large changes in abundance ratios near regions of closed neutron shells. In the present work element abundances from Sn to Ir were computed on the rapid process for two sets of parameters: $Q_n=2.0$ Mev, $n_n=10^{24}$ per cm³, $T=10^9$ °K, and $Q_n=3.0$, $n_n=10^{24}$, $T=1.5\times10^9$ (alternatively the latter could be $n_n=10^{19}$ at $T=10^9$). The general behavior is that just after shell closure at 82 neutrons the abundance ratio $N(Q_n=3.0)/N(Q_n=2.0)$ is near one, following which it rises rapidly to a value of several hundred. The ratio then drops rapidly to the vicinity of 10 and is approximately maintained there until shell closure at 126 neutrons. At this point the ratio falls again to about one.

J14. New Neutron Sources of Astrophysical Interest. A. G. W. CAMERON, *Atomic Energy of Canada Ltd.*—It has been suggested that the reactions $C^{13}(\alpha,n)O^{16}$ and $Ne^{21}(\alpha,n)Mg^{24}$ may provide neutron sources which are responsible for the formation of heavy elements by neutron capture on a slow time scale. However, there is now considerable doubt that either reaction will provide enough neutrons to do this. Hence most heavy element formation on a slow time scale in stars may be a consequence of the following processes: At 6×10^8 °K the $C^{12}(C^{12},p)Na^{23}$ and $C^{12}(C^{12},\alpha)Ne^{20}$ reactions take place with an estimated branching ratio of 1:2. The products cause the reactions $C^{12}(p,\gamma)N^{13}(\beta^+\nu)C^{13}$ and $C^{13}(\alpha,n)O^{16}$ to take place. At 1.3×10^9 °K the reaction $O^{16}(O^{16},n)S^{31}$ occurs, accompanied by $O^{16}(O^{16},p)P^{31}$ and $O^{16}(O^{16},\alpha)Si^{28}$. Both sets of reactions can cause heavy element formation by neutron capture on a slow time scale; the latter set of reactions is particularly interesting because certain (γ,n) reactions can slow down the flow of nuclei into the heavy element region. Thus it is desirable that neutron capture cross-section measurements should be made in the laboratory for neutron energies near 60 and 140 kev.

FRIDAY MORNING AT 9:30

Willard, Grand Ballroom

(H. D. SMYTH presiding)

Plasma, II

JA1. Lack of Magnetic Confinement of a Plasma. JOSEPH SLEPIAN, *Pittsburgh.*—A straight circular tube having a wall which removes all particles which strike it is said to have a time constant for the disappearance of the contained fully ionized gas, which is lengthened by a factor of 10^5 or more by the imposition of a straight longitudinal magnetic field. This is not borne out by experiment or by closer analysis. Taking a circular symmetrical distribution of ions and electrons, and using the same notation as LS,[1] we get from Eq. (2–11), when corrected, and from Eq. (2–12) when modified by omission of negligibly small terms, for the radial component, the equation

$$\rho\left(\frac{d\mathbf{v}}{dt}\right)_r=\rho\left(\frac{\partial\mathbf{v}}{\partial t}+\mathbf{v}\cdot\nabla\mathbf{v}\right)_r=-\frac{\partial p_i}{\partial r}+\frac{\rho}{m_i}\frac{e}{c}\mathbf{E}_r$$

independently of the magnetic field used. The terms are hardly changed by the magnetic field, so that the time constant is but little affected.

[1] LS is the abbreviation for Lyman Spitzer, Jr., *Physics of Fully Ionized Gases* (Interscience Publishers, Inc., New York, 1956).

JA2. Stability of a Cylindrical Plasma Compressed by an Increasing External Magnetic Field. R. L. MOORE, *Richard L. Moore Consultants.**—The equations of motion used to treat pulsating stars as developed by Eddington[1] and others are used with the boundary condition, $\partial p/\partial r]_0=-H_0^2/4\pi r_0$. Stability considerations of the plasma in an oscillating magnetic field predict the critical (inward) velocity as $V_0=-(2r_0\dot{H}_0)(1+\gamma)^{-1}H_0^{-1}$. Oscillations are predicted at the

natural frequency and forcing given by the differential equation $(\partial^2 V/\partial t^2)+(H^2/4m)(\gamma+1)V=-(r/2\pi m)(\dot{H}H)$.

* Work supported by Norair, a Division of Northrop Corporation.
[1] S. Rosseland, *Pulsation Theory of Variable Stars* (Oxford University Press, New York, 1949).

JA3. Some Hydromagnetic Equilibria.* JOHN M. GREENE, JOHN L. JOHNSON,† AND HAROLD R. KOENIG,‡ *Project Matterhorn.*—Hydromagnetic equilibria have been obtained for a variety of situations which differ little from that of a zero pressure uniform axial magnetic field. The perturbations considered are particle pressure, axial current, curvature of the system, and multipolar fields. These equilibria differ from those which have been obtained previously[1] in that the lowest order term in an asymptotic expansion of the magnetic surface is not cylindrically symmetric but is a function of both r and θ. The problem is reduced to the solution of a second-order nonlinear partial differential equation. If it is assumed that the lowest order terms in the expressions for the material pressure and axial current distributions are of the form $a+b\Psi_0$ where a and b are constants and Ψ_0 is the zeroth-order magnetic surface, the equation is linear and can be integrated directly. The solution will be given and the magnetic surface and rotational transform will be shown for some simple configurations.

* Supported by the U. S. Atomic Energy Commission.
† On load from Westinghouse Electric Corporation, Atomic Power Department.
‡ On loan from General Electric Company, Central Engineering Laboratory, 1955–1957.
[1] Johnson, Oberman, Kulsrud, and Frieman, Phys. Fluids 1, 281 (1958).

JA4. Absorption of Plasma Waves. THOMAS H. STIX, *Project Matterhorn.*—We consider the passage of a wave through a region of plasma in which parameters such as the ion density and the magnetic field strength may be functions of position. Such nonuniformities are characteristic of practical plasma containment devices. If the variation of the parameters is sufficiently slow, the character of the wave may be found by an adiabatic approximation. The connection of these adiabatic solutions on each side of a turning point depends on the nature of the turning point. Zeros and poles in the square of the propagation constant give rise to linear and singular turning points (ltp) and (stp), respectively. The ltp is mathematically identical to the linear WKB connection in quantum mechanics, and the stp may be handled analogously. An incoming wave is reflected at an ltp, but absorbed at an stp. If the stp wave equation is written $E''+\mu(x+i\epsilon)^{-1}E=0$, where μ and ϵ are real, and $|\mu\epsilon|\ll 1$, half of the power in the wave is absorbed in the interval $x=\pm\epsilon$. Collisions and fine scale mixing provide the mechanism for absorption. The absorption may be used for plasma heating or diagnostics.

JA5. Oscillations of a Finite Cold Plasma in a Strong Magnetic Field. JOHN DAWSON AND CARL OBERMAN, *Project Matterhorn.*—Of prime concern in plasma investigations is the coupling of a bounded plasma with external electromagnetic fields. In the present paper the properties of the normal modes of a cold plasma slab, and cylinder, situated in a strong magnetic field are derived, and then used to discuss the transmission and reflection of radiation, the scattering by a plasma cylinder, the response to driving sources in the vicinity of the plasma, and the radiation due to plasma oscillations.

JA6. Diamagnetic Effects in a Rotating Plasma.* D. A. BAKER AND F. L. RIBE, *Los Alamos Scientific Laboratory.*—Magnetic probes have been applied to the Los Alamos rotating-plasma device, Ixion,[1,2] which utilizes deuterium plasma injection into orthogonal electric and magnetic fields in a mirror geometry. Two probes were used to measure the axial magnetic field changes at various radial and axial positions. The measured distributions of magnetic field show the presence of centrifugal effects arising from the mass difference of the ions and electrons. The field distribution along the axis shows the plasma diamagnetism to be located in the region between the magnetic mirrors. After its onset, the diamagnetism decays in a period ($\sim$200 μsec) identical with that of the applied voltage. These results give an indication of the improved mirror confinement which is expected to arise from the plasma rotation. From the variation of magnetic field with radius one can identify Larmor (cyclotron) motion as well as the diamagnetism due to the centrifugal forces in the rotating plasma.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] Boyer, Hammel, Longmire, Nagle, Ribe, and Riesenfeld, Second International Conference on the Peaceful Uses of Atomic Energy, September, 1958.
[2] Boyer, Hammel, Longmire, Nagle, Ribe, and Riesenfeld, U. S. Atomic Energy Commission, Washington, Controlled Thermonuclear Conference, Rept. TID-7558, p. 140, 1958.

JA7. Optimum Power Generation Using a Plasma as the Working Fluid. JOSEPH L. NEURINGER, *Republic Aviation Corporation.*—The possibility exists of directly using the plasma, resulting from a controlled fusion reaction, to generate electricity by electromagnetic induction. The problem considered here is the steady one-dimensional motion of a plasma in a channel of arbitrary and slowly varying cross section. The plasma flows across a transverse magnetic field of arbitrarily varying strength, and the conducting channel walls are connected to an external resistive load of arbitrary magnitude. We ask, "For a channel of given entrance cross section and length, what must be the shape of the channel, distribution of magnetic field strength, and external loading so that maximum power may be extracted by the external load?" The extremum problem is formulated using the techniques of the calculus of variations to obtain the appropriate system of differential equations and boundary conditions. For the special cases where the differential constraints, i.e., the fluid flow equations, are integrable, analytical solutions are obtained exhibiting the dependence of the required loading on the magnetic Reynolds' number and the flow Mach numbers based on the sonic and Alfvén wave speeds. The efficiency, terminal voltage, and distribution of the fluid mechanical variables along the channel are also presented as functions of the above dimensionless parameters.

JA8. Boundary Layer Formation in the Pinch.* S. A. COLGATE, G. GIBSON, AND J. KILLEEN, *University of California, Livermore.*—A study is being made of various processes that occur prior to the pinch effect when an electric field is applied to a deuterium gas. The variables of the problem are the percentage of ionization, the electron and ion temperatures, the resistivity of the gas, and the current density. We consider a one-dimensional problem, i.e., the above variables are determined as functions of one space dimension and the time. The equations determining these variables are: the heat developed as the current flows through the gas equals the rate of increase of the internal energy of the plasma, the equation describing the rate of ionization, the equation describing the rate of transfer of energy from electrons to ions, and the electromagnetic field equations. These equations are a generalization of the plasma equations solved in the paper of Wyld and Watson[1] in that spatial dependence is included, i.e., a current layer is calculated instead of assuming a constant current. The boundary condition for the current density is derived by taking the electric field at the wall to be the constant applied field and an inductive term. The equations are solved numerically using an IBM 704 computer.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

JA9. Circuit Dynamics of the Pinch.* J. KILLEEN AND B. A. LIPPMAN, *University of California, Livermore.*—Instead of analyzing in detail a portion of a hydromagnetic pinch apparatus and replacing the remainder by a boundary condition, the entire pinch apparatus is treated here as a single dynamical system. A circuit equation and a mechanical equation, coupled together, result. These equations describe the dynamical development of the pinch and exhibit explicitly its dependence on the physical parameters (electrical and mechanical) of the system. As examples, the equations have been used to analyze the snow-plow model and the adiabatic pinch, yielding curves that show the geometrical development of the pinch in time, as well as the distribution of mechanical and magnetic energies at any stage. Analogous analyses may be made for other physical quantities of interest, and can be used to adjust the parameters of the system so as to optimize specific pinch characteristics.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

JA10. Stabilized Tubular Pinch.* A. N. KAUFMAN AND W. A. NEWCOMB, *University of California, Livermore.*—The conventional stabilized pinch configuration is characterized by a cylindrical plasma column, stabilized by an applied axial magnetic field B_z, and carrying an axial current that produces an azimuthal field B_θ external to the plasma column. In the unstabilized tubular pinch,[1] the plasma fills an annular region, and is confined by both internal and external azimuthal fields, the former being produced by an axial current-carrying conductor. The tubular pinch, like the conventional one, can be stabilized by an axial magnetic field. The conditions for this stabilization have been derived[2] from the hydromagnetic energy principle.[3] It is found, in particular, that a thin tubular pinch is stable whenever B_θ decreases monotonically through the plasma layer without reversing its direction, provided that the plasma pressure is sufficiently small.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] W. R. Baker *et al.*, Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1958, Paper No. 2349.
[2] A. N. Kaufman and W. A. Newcomb, "Hydromagnetic stability of a tubular pinch," UCRL-5434.
[3] Bernstein, Frieman, Kruskal, and Kulsrud, Proc. Roy. Soc. (London) **A244**, 17 (1958).

JA11. Electron Beam Transmission along a "Stabilized Pinch."* R. T. SPOERLEIN, D. H. BIRDSALL, S. A. COLGATE, AND H. P. FURTH, *University of California, Livermore.*—As has been pointed out previously,[1] the so-called "stabilized pinch" is subject to small-scale instabilities that permit electrons to escape to the tube wall. This leakage of electrons was studied indirectly by means of the soft x-rays produced. In order to obtain direct evidence regarding nonadiabatic influences on electron behavior in the turbulent surface layer of the pinch, a 200- to 300-kev, 200-ma electron beam is now being used as a probe. This beam is passed axially through an end electrode into a 5 kv, 250-ka linear pinch of 3-in. initial diameter. The position of beam traversal through the pinch can be varied by means of a magnetic deflector. The beam is pulsed on for a fraction of a microsecond during the 10-μsec pinch cycle, and creates a "picture" of the pinch surface on a zinc sulfide phosphor shielded by an aluminum foil, which is located at the far electrode.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Colgate, Ferguson, and Furth, "The stabilized pinch," Second International Conference on the Peaceful Uses of Atomic Energy, No. 376, Geneva, Switzerland, 1958.

JA12. Study of the Generalized Pinch Configuration.* S. A. COLGATE, D. H. BIRDSALL, J. P. FERGUSON, H. P. FURTH, AND F. HALLIDAY, *University of California, Livermore.*—Intensive study has been given at many laboratories to pinches where an external B_θ presses against an internal B_z or against plasma inertia. In an ingenious variant,[1] plasma is compressed between an internal and external B_θ of opposite sign. Aside from these special cases, there exist, of course, many other pinch configurations, with assorted values of internal and external B_θ and B_z. Some of these are being studied by us in a 10-in. linear pinch tube with a 3-in. insulated center conductor (used to set up the internal B_θ). Among the generalized configurations are some expected to possess a much higher degree of hydromagnetic stability than the ordinary "stabilized pinch." The observed peristence of small-scale turbulence in these cases suggests that basic nonhydromagnetic troubles are present. These may be distorting the expected plasma and field configurations in such a way as to precipitate hydromagnetic instability.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] O. A. Anderson and W. R. Baker, "The tubular pinch," Second International Conference on the Peaceful Uses of Atomic Energy, No. 332, Geneva, Switzerland, 1958.

JA13. High-Gradient High-Frequency Pinch Assembly. V. JOSEPHSON, L. O. HEFLINGER, S. L. LEONARD, AND J. R. PENNING, *Space Technology Laboratories* (introduced by B. D. Fried).—An experimental device has been assembled which was designed to apply very high gradients ($\sim$100 kv/cm) to an ionized gas column for short periods of time in an attempt to produce very energetic (10 kev) deuterons by a superfast pinch. Previous discussions of the theory and experimental assembly were given by Fried and Josephson at the Washington Sherwood Meeting,* February, 1958. Although the very energetic deuterons have not as yet been attained, the component developments and their characteristics are of interest. They include (a) a condenser and inductive load assembly with a ringing frequency of 20 mc/sec, and I_p of 10^5 amp at 300 kv, (b) a fast high-voltage switch which holds off $>$300 kv with switching times $<$0.1 μsec, (c) a resonant transformer supply capable of furnishing 1500 j of energy at 10^6 v, (d) a fast smear camera with writing speeds of $\sim$500 mm/μsec, (e) a plasma generating device capable of producing $\sim$10 ev plasmas at 10^{16}/cc, and (f) current measuring devices giving absolute values of $I(t)$ and $I(r)$. Smear pictures and current traces obtained with the assembly will be shown and possible interpretations given.

* TID 7558 Controlled Thermonuclear Conference.

JA14. Damage Probe Measurements in a Pulsed Discharge.* R. TUCKFIELD AND F. R. SCOTT, *General Atomic.*†—In pulsed discharges, such as a pinch, it is advantageous to know the time and amount of energy being dissipated at the wall. It is possible to measure this in an integral manner by placing a thin film of metal, backed by a transparent insulator, at the wall of the discharge. The metal is then viewed through the insulator by a smear camera. The metal film and insulator are called a damage probe. When this probe (1200 A of aluminum) was placed directly in the path of a shock it became transparent in approximately 1 μsec after contact with the pressure front. If the film was completely evaporated it received >0.1 cal/cm^{-2} μsec^{-1}. A 2400-A film took approximately 2 μsec. Results will be given for both the shock tube and the pinch discharge using various thicknesses and higher Z metals.

* This work was done under a contract between General Atomic and the Texas Atomic Energy Research Foundation.
† John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.

FRIDAY MORNING AT 9:30

Commerce Auditorium

(W. A. NIERENBERG presiding)

Electric Dipole Moments; Magnetic Resonance, I

K1. Experiments to Detect an Electric Dipole Moment of the Free Electron.* D. F. NELSON, A. A. SCHUPP, R. W. PIDD, AND H. R. CRANE, *The University of Michigan.*—The results of the g-factor experiment place an upper limit on the EDM of the electron, of 3×10^{-18} cm (times the electronic charge). We are now modifying the experiment to give a smaller upper limit. The scheme is to apply a small (~20 v/cm) radial electric field, which will reduce the spin precession around the magnetic field direction to exactly the cyclotron frequency. The electric field will be switched on at a time when the polarization is parallel to the velocity. If no EDM exists, the spin will remain in this orientation. If there is an EDM, there will be a slow precession around the radius ($B\times v$) direction, and this will be observable with analyzer counters placed in the radial direction. If an upper limit of 1 cps can be placed upon the EDM precession, an upper limit of 7×10^{-20} cm will be indicated. Effects due to the helicity of the orbits and stray electric fields will limit the ultimate accuracy, but preliminary calculations indicate that a limit of 10^{-17} cm may be quite feasible.

* Supported by the U. S. Atomic Energy Commission.

K2. Upper Limits of Nuclear Electric Dipole Moments. MYER BLOOM, *University of British Columbia.*—Experiments to detect possible nuclear electric dipole moments are difficult to conceive because nuclei are charged. The confinement of a nucleus for an appreciable time to an experimental apparatus of reasonable dimensions requires the time-averaged electric field at the nucleus to be zero. However, the fluctuating electric fields due to lattice oscillations in solids are calculated to produce effects in nuclear magnetic resonance experiments which enable a smaller upper limit to be placed on the electric dipole moments of some nuclei than was heretofore possible. For an electric dipole moment of magnitude $\lambda e(10^{-13}$ cm), three types of experiments are analyzed. (1) Anisotropic lattice oscillations produce second-order perturbations to nuclear spin levels. Interpretation of the experiments of Robinson, Volkoff, and others on the Al^{27} resonance in spodumene[1] gives $\lambda \lesssim 1$ for Al^{27}. (2) Nuclear spin relaxation due to the nuclear electric dipole interactions will predominate over quadrupolar effects[2] unless $\lambda \lesssim 10^{-3}$ for nuclei having typical electric quadrupole moments. (3) Induced ultrasonic absorption experiments on nuclei having spin $\frac{1}{2}$ and hence zero quadrupole moments offer possibilities of upper limits smaller than (1) and (2).

[1] L. B. Robinson, Can. J. Phys. **36**, 1295 (1958).
[2] J. van Kranendonk, Physica **20**, 781 (1954).

K3. Experimental Results on the g-Factor Anomaly of the Free Electron.* A. A. SCHUPP, R. W. PIDD, AND H. R. CRANE, *The University of Michigan.*—The experiment yields a value $|(g/2)-1| = 0.0011612\pm0.0000024$ for free electrons in the range 60 to 100 kev. The method, as previously described,[1] is to polarize the beam by Mott scattering, trap the electrons in a magnetic field having a slight "betatron shape," and analyze the polarization by a second scattering. The difference between the frequencies of the cyclotron motion and the spin precession is measured. The difference frequency is proportional to the anomalous part of the g factor. Electrons are trapped for over 100 revolutions of the polarization direction relative to the velocity (~80 000 cyclotron revolutions). The principal sources of error are the determination of the effective magnetic field in the trap, the measurement of the difference frequency, and the estimate of the upper limit on stray electric fields in the trap. These sources of error will be discussed, and possibilities for extension of the accuracy will be noted.

* Supported by the U. S. Atomic Energy Commission.
[1] Crane, Pidd, and Louisell, Phys. Rev. **91**, 475 (1953).

K4. Precise Determination of the Triton Moment in Units of the Proton Moment. WILLIAM THOMAS DUFFY, JR., *Stanford University* (introduced by F. Bloch).—A 200-curie sample of 20% tritiated water (H_2O, T_2O, HTO) was used in a high-resolution nuclear magnetic resonance apparatus to make a precise determination of the moment ratio. A ratio of Larmor frequencies of 1.06663975 (2) was measured in a field of about 7164 gauss. The unknown difference in magnetic shielding introduces an estimated error which is about five times the experimental error, giving a moment ratio of 1.06663975 (10). Using this value and the results obtained by Prodell and Kusch[1] from the hfs of tritium, one finds that the hfs anomaly of tritium is $-5.52\ (14)\times10^{-4}$. This value falls within the range of calculated values obtained from various theoretical assumptions.[2] The longitudinal relaxation times at room temperature were observed to be 1.02 ± 0.10 sec for protons and 0.83 ± 0.10 sec for tritons. The former represents a reduction by a factor of about 2.5 from the relaxation time of protons in pure water and is, perhaps, caused by the free radicals[3] produced by the beta activity.

[1] A. Prodell and P. Kusch, Phys. Rev. **106**, 87 (1957).
[2] E. Adams, Phys. Rev. **81**, 1 (1951).
[3] Dousmanis, Sanders, and Townes, Phys. Rev. **100**, 1735 (1955).

K5. Nuclear Magnetic Resonance of B^{11} in the Binary Glass K_2O-B_2O_3.* J. G. O'KEEFE AND P. J. BRAY, *Brown University.*—The nuclear magnetic resonance of B^{11} has been investigated in the K_2O-B_2O_3 system up to a concentration of 30 molar % K_2O. The B^{11} spectrum consists of a narrow line arising from an $m=\frac{1}{2}-\frac{1}{2}$ transition, not noticeably perturbed by second-order quadrupolar effects, superimposed on a second-order quadrupolar broadened $m=\frac{1}{2}-\frac{1}{2}$ transition. The spectrum exhibits the same general characteristics as reported for the Na_2O-B_2O_3[1,2] and Li_2O-B_2O_3[2] binary systems. As the alkali metal oxide is added to the B_2O_3 system the B^{11} changes its coordination number from 3 to 4. The rate at which this change in coordination number occurs differs in the three systems. This rate is largest for the Li_2O-B_2O_3 system and smallest for the Na_2O-B_2O_3 system.

* Research supported by the U. S. Atomic Energy Commission.
[1] Silver, O'Keefe, and Bray, Bull. Am. Phys. Soc. Ser. II, **2**, 225 (1957).
[2] A. H. Silver and P. J. Bray, J. Chem. Phys. **29**, 984 (1958).
[3] Silver, O'Keefe, and Bray, Bull. Am. Phys. Soc. Ser. II, **3**, 21 (1958).

K6. Nuclear Spin of Br^{77}.* T. M. GREEN, H. GARVIN, E. LIPWORTH, AND K. SMITH, *University of California, Berkeley.*—The nuclear spin of 57-hr Br^{77} has been measured by the method of atomic beams. The isotope is produced by an $(\alpha,2n)$ reaction using the 38-Mev beam from the Berkeley 60-in. cyclotron. Bromine atoms are formed in a quartz rf discharge tube and detected by their radioactive decay, after collection on silver-coated buttons. For Br^{77} the spin is found to be $\frac{3}{2}$, and because $I=J=\frac{3}{2}$ both flop-in transitions occur at the same frequency, at low magnetic fields. The resonance has been observed at five different magnetic fields up to 48 gauss. A spin of $\frac{3}{2}$ is expected from the previously observed spins of $\frac{3}{2}$

for Br^{79} and Br^{81},[1] which differ from Br^{77} by 1 and 2 pairs of neutrons, respectively. Work is being continued to obtain values of the hyperfine-structure separations, magnetic moment, and electric quadrupole moment of this isotope.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] J. G. King and V. J. Jaccarino, Phys. Rev. **94**, 1610 (1954).

K7. Nuclear Spin of Praseodymium/142.* R. MARRUS, A. CABEZAS, E. LIPWORTH, AND J. WINOCUR, *University of California, Berkeley.*—The nuclear spin of 19.6 h Pr^{142} has been determined by the method of atomic beams. Pr^{142} was prepared by neutron bombardment of stable Pr^{141} in a pile. The beam was formed using a tantalum oven with tantalum slits and collected upon flamed platinum foils. The beam was detected by counting the 2-Mev decay β particle in continuous flow proportional counters. Resonances have been observed at fields of 2.1 and 4.2 gauss in the $J=9/2$ state and the observations are consistent with an assignment of 2 for the nuclear spin. The spin of 2 confirms an earlier assignment made by a study of the β spectrum.[1] An incidental result of this work is a confirmation of the g_j value previously reported by Lew.[2]

* This work supported by the U. S. Atomic Energy Commission.
[1] Pohm, Lewis, Talboy, and Jensen, Phys. Rev. **95**, 1523 (1954).
[2] H. Lew, Phys. Rev. **91**, 619 (1953).

K8. Nuclear Spin of Eu^{152m} by Atomic Beams.* R. A. NOVICK,† V. W. COHEN, AND J. SCHWARTZ, *Brookhaven National Laboratory.*—In the course of investigations in the nuclear spectroscopy of Eu^{152} it was concluded by Goldhaber and others that the spin of the 9.3-h isomer was most likely 0. The atomic beam technique cannot positively establish a zero spin. It can, however, determine definitely a nonzero spin if the magnetic interaction is appreciable. A magnetic resonance "flop-in" type of experiment was performed and revealed a single resonance line with frequency linear in field over the range of 0.8 to 1.4 gauss and of a line width of 130 kc. This frequency is consistent with an assumption of a spin of zero. If the spin were not zero but the magnetic interaction were very small we would observe the transitions $m_j(-\frac{1}{2}\leftrightarrow+\frac{1}{2})$, $\Delta m_i=0$ which would give a multiplet which might not be resolved. If this were the case the total spread of the spectrum would have to be appreciably less than our observed 130 kc. For a nuclear spin of 1 this would require an A coefficient of not over 50 kc. By comparison with Eu^{151} for which the value of hfs constant $A=20$ mc and $\mu=3.6$ this would imply a magnetic moment of less than 4×10^{-3} nm.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Permanent address: University of Illinois.

K9. Field Gradients at the Deuteron in Molecules. R. BERSOHN, *Cornell University.*—Various matrix elements of the field gradient tensor at the deuteron have been computed for D_2, $\equiv C-D$, and D_2O. Except perhaps in a negative ion the field gradient will always be positive because the electron distribution is too diffuse to cancel the positive field gradient coming from the nuclei. The calculated electronic contributions are too small in magnitude except for D_2; comparison with D_2 indicates that in other hydrides introduction of an effective nuclear charge $\neq1$ in the hydrogen 1s function will improve the calculated field gradients. The quadrupole coupling constant should decrease with increasing ionic character of a bond D−M because charge placed on atom M produces a larger field gradient than charge on the deuteron. The qcc should increase with increasing atomic number of M as the electrons of the larger atoms cancel a smaller fraction of the field gradient originating from the nucleus of atom M. Experiment shows that the latter effect dominates.

K10. Nuclear Quadrupole Interaction in Beryllium Metal.* M. POMERANTZ, *Centre d'Etudes Nucleaires de Saclay,* AND T. P. DAS,† *University of Illinois.*—The theory for the origin of the field gradients at nuclei in metals has been analyzed. The contributions of the ion cores and conduction electrons have been separately considered. In the case of Beryllium metal, using orthogonalized plane wave functions, the conduction electrons are shown to enhance, by about 8%, the field-gradient due to the ion cores. Combining the results of our calculations with Knight's[1] observed value of 48 kc for the Be^9 coupling constant e^2qQ/h, a value of $Q=0.029\times10^{-24}$ cm^2 is obtained.

* A major portion of this work was performed while the authors were at the University of California, Berkeley.
† On leave of absence from Saha Institute of Nuclear Physics, Calcutta.
[1] W. D. Knight, Phys. Rev. **92**, 539A (1953).

K11. Effects of the Crystalline Defects on Pure Quadrupole Resonance.* J. L. RANDALL, W. G. MOULTON, AND W. B. ARD, JR., *University of Alabama.*—The effects of x-irradiation, pressure, and additive impurities on the chlorine quadrupole resonance line have been studied in sodium chlorate, potassium chlorate, and p-dischlorobenzene. The studies were made with a regenerative spectrometer so that the detailed line shapes could be observed. Changes in the second moment, line width, and integrated intensity, as a function of irradiation time, pressure, and percent impurity, were measured. An increase in the second moment and in the line width was observed in all cases, and a decrease in integrated intensity was observed in a few cases. Comparison of the data with the theory of the broadening of quadrupole lines by charge and size defects will be presented.

* This work supported by the Research Corporation.

K12. Knight Shift of Indium in a Lead-Indium Alloy. LAWRENCE H. BENNETT, *National Bureau of Standards.*—The nuclear magnetic resonance absorption of In^{115} has been observed in a lead-indium alloy containing 5 at % indium. The large quadrupole moment of indium renders the nuclear magnetic resonance unobservable in the tetragonal lattice of pure indium, but permits the observation of the central component in the cubic alloy chosen here. The satellite lines are smeared out due to the absence of complete local cubic symmetry. The measured value of the Knight shift of In^{115} in the alloy relative to In^{115} in the semiconductor InSb is 0.85%. This is in reasonable agreement with an estimate of the Knight shift based on the assumption that the indium atoms form impurity states and "see" the electronic structure of the conduction band of pure lead.

K13. Nuclear Magnetic Resonance Shifts in Stable Free Radicals. M. E. ANDERSON, T. R. TUTTLE, JR., AND G. E. PAKE, *Stanford University.*—McConnell[1] and others have pointed out that hyperfine coupling constants may be determined from shifts of nuclear resonance lines in paramagnetics with sufficiently rapid electron spin-lattice relaxation or exchange interaction. Measured shifts give the coupling magnitude in these cases of unresolved electron hyperfine structure, and they fix the sign of the coupling or spin density[2] without requiring very low temperatures. We have examined proton resonances from several free radical crystals. Often the shifts are smaller than anticipated and therefore difficult to resolve.

The extensive departure at 77°K from prediction based on measured hyperfine splittings for Wurster's blue perchlorate is partially attributable to anomalous temperature dependence of the paramagnetic susceptibility.[3]

[1] H. M. McConnell and C. M. Holm, J. Chem. Phys. **27**, 314 (1957).
[2] H. M. McConnell and D. B. Chestnut, J. Chem. Phys. **28**, 107 (1958).
[3] N. Elliott and M. Wolfsberg, Phys. Rev. **91**, 435A (1955).

K14. Spin-Lattice Relaxation in Sodium Nitrate.* WALTER I. GOLDBURG, *Carnegie Institute of Technology.*—If a single

crystal of $NaNO_2$ is oriented in a strong magnetic field so that the quadrupole splitting is large and the four sodium sublevels are not equally spaced, spin-lattice relaxation is characterized in general by three transition probabilities: $W_1(\pm\frac{1}{2} \leftrightarrow \pm\frac{3}{2})$, $W_2(\pm\frac{1}{2} \leftrightarrow \mp\frac{3}{2})$, and $W_3(-\frac{1}{2} \leftrightarrow \frac{1}{2})$. If the relaxation is purely quadrupolar, $W_3=0$. The ratios W_2/W_1 and W_3/W_2 were measured at $\theta=0.0°$ (in the notation of Pound[1]). The method is to saturate one pair of levels with intense rf [which remains on much longer than $(W_1)^{-1}$] and then to observe, by nuclear resonance pulse techniques, the three signal intensities immediately after the rf is turned off.[1] The measurements gave $W_2/W_1=0.90\pm0.05$, $W_3/W_2<0.10$. One can also determine W_1, W_2, and W_3 by observing the rate of recovery of each of the three resonance signals following saturation by a short pulse. These experiments were done at $\theta=0.0°$ and at an angle where the level spacings are (almost) equal. In the latter case relaxation is characterized by a single time $T_1^*=5(2W_1+8W_2+W_3)^{-1}$. Preliminary measurements reveal an angular dependence of W_1 and W_2. All measurements were made at 77°K where $(2W_1)^{-1}\simeq 1$ min.

* Supported in part by the National Science Foundation.
[1] R. V. Pound, Phys. Rev. **79**, 685 (1950).

FRIDAY MORNING AT 9:30

WILLARD, South Ballroom

(W. SELOVE presiding)

Invited Paper

KA1. Interactions of Polarized Protons with Nucleons and Light Nuclei. RICHARD WILSON, *Harvard University.* (30 min.)

Elastic Scattering of Elementary and Other Particles

KA2. Polarimeter for 100-200 Mev Protons. E. HEER, J. TINLOT, W. GIBSON, AND A. ENGLAND, *University of Rochester.**—In connection with a program to determine the p-p scattering matrix at 205 Mev we have built, tested, and calibrated a polarimeter for high-energy protons. The instrument measures the proton polarization by measuring the left-right asymmetry in scattering from carbon in an angular range of 9° to 14°. A double scintillation telescope monitors the incident beam and two triple telescopes detect left- and right-scattered protons. Left and right telescopes are periodically interchanged by rotating the polarimeter about an axis optically aligned with the beam direction. The instrument has been calibrated as a function of proton energy using an energy-degraded 90% polarized proton beam. The most favorable target and absorber thicknesses were chosen for seven energies ranging from 102.5 to 191.3 Mev, corresponding to the energies of 205-Mev protons scattered from protons through c.m. angles of 30°, 40°, 50°, 60°, 70°, 80°, and 90°. The observed asymmetries are, respectively, 0.578 ± 0.006, 0.499 ± 0.005, 0.434 ± 0.004, 0.454 ± 0.017, 0.314 ± 0.007, 0.218 ± 0.013, and 0.159 ± 0.013. The quoted errors are statistical. We estimate the systematic errors to be smaller than 0.01 in all cases.

* Supported in part by the U. S. Atomic Energy Commission.

KA3. Proton-Proton Triple Scattering at 205 Mev. J. TINLOT, E. HEER, A. ENGLAND, AND W. GIBSON, *University of Rochester.**—As part of a program to determine the p-p scattering matrix at 205 Mev, we have measured the rotation parameter R in a triple scattering experiment. A 90% polarized proton beam was scattered from liquid hydrogen in a plane containing the incident polarization vector, and the transvrese component of the polarization in the second scattering plane measured using the polarimeter described in the preceding paper. The ratio of the measured polarization to the incident beam polarization is the quantity R. The results are given in Table I. (The quoted systematic errors are upper limits based on an estimated upper limit of 0.01 in the measured asymmetries.) These results will be compared with predictions[1] based on the phenomenological models of Signell and Marshak[2] and Gammel and Thaler.[3]

TABLE I.

c.m. angle, θ	30	40	50	60	70	80	90
$R(\theta)$	−0.210	−0.169	−0.061	+0.018	+0.139	+0.256	+0.197
$\pm\delta R$ (statistical)	0.013	0.019	0.021	0.033	0.031	0.062	0.056
$\pm\delta R$ (systematic)	0.02	0.02	0.02	0.02	0.03	0.05	0.06

* Supported in part by the U. S. Atomic Energy Commission.
[1] R. A. Bryan (private communication).
[2] P. S. Signell and R. E. Marshak, Phys. Rev. **109**, 1229 (1958).
[3] J. L. Gammel and R. M. Thaler, Phys. Rev. **107**, 291 (1957); **108**, 163 (1957).

KA4. Proton-Proton Scattering at 68 Mev.* DONALD E. YOUNG AND LAWRENCE H. JOHNSTON, *University of Minnesota.*—The differential proton-proton scattering cross section has been measured at 68.3 Mev using the Minnesota Proton Linear Accelerator and the small-angle scattering chamber previously described.[1] The scatterer is hydrogen gas at a pressure of 1 atmos. Measurements have been made at 26 angles from 5° to 50° (lab) with $\pm\frac{1}{4}$° resolution from 5° to 18° and ±2° from 18° to 50°. The errors have been estimated to be $\pm\frac{1}{2}$% relative and ±1% absolute. The differential cross section (center-of-mass system) goes through a minimum at 8° (lab), then rises by a factor of 3 between 8° and 5°. At larger angles, the cross section (center-of-mass) displays a maximum between 17° and 30° falling off to a constant value of 6.16 mb per sterad between 37° and 50°.

* Supported in part by the U. S. Atomic Energy Commission.
[1] L. H. Johnston and D. A. Swenson, Phys. Rev. **111**, 212 (1958).

KA5. Proton-Proton Polarization at 16 Mev.* W. A. BLANPIED, *Princeton University*, AND K. W. BROCKMAN, *Institut voor Kernphysisch Onderzoek, Amsterdam.*—The proton-proton polarization has been measured at an energy of about 16 Mev and an angle of 25° in the laboratory system. Measurements were made using the usual double scattering method, with carbon and copper serving alternately as first scatterers. Polarization data on these nuclei are known from

previous work at Princeton.[1,2] It will be shown that the alternation of these first targets serves to minimize certain of the instrumental asymmetries. Hydrogen at 100 psi, contained in a scatterer previously described by one of us[1] and modified for this work, was the second target. A counting rate of about 1 per 3 min on each side was obtained in this setup. Preliminary data show a small, but not necessarily zero polarization.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] K. W. Brockman, Phys. Rev. 110, 163 (1958).
[2] W. A. Blanpied, Phys. Rev. (to be published).

KA6. Polarization in Proton-Proton Scattering at 3.5 Mev.* I. ALEXEFF, R. I. BROWN, R. A. LUX, S. J. MOSS, AND W. HAEBERLI, *University of Wisconsin.*—Polarization in proton-proton scattering for proton energies near 3.5 Mev has been measured for scattering angles of 30°, 45°, and 53° c.m. According to Hull and Shapiro,[1] polarization up to 4% might be possible. The statistical error in our results is ±0.2%. At present results are accurate only to ±1%, because corrections for instrumental asymmetries have not been evaluated completely. Within this limit no polarization has been detected. More accurate data will be presented. Helium was used as an analyzer. The gas density in polarizer and analyzer scattering regions was locally increased by cooling with liquid air. Coincidence techniques reduced background to less than 1%.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.
[1] M. H. Hull, Jr., and J. Shapiro, Phys. Rev. 109, 846 (1958).

KA7. Neutron-Proton Total Cross-Section Measurement at 4.5 Bev.* VICTOR PEREZ-MENDEZ, JOHN H. ATKINSON, WILMOT N. HESS, AND ROGER W. WALLACE, *University of California, Berkeley.*—The *n-p* total cross section was measured at the Bevatron by using a beam of neutrons of mean energy 4.5 Bev incident on a liquid hydrogen target. For this measurement we used the same experimental arrangement reported previously for measurements of total and reaction cross sections on various elements.[1] The neutron-counter telescope detects the charged pions produced by the neutrons in a beryllium converter; the effective neutron energy of $4.5_{-1.0}^{+1.0}$ Bev is determined at the lower limit by the pion-detection threshold of a gas Cherenkov counter, and at the upper limit by the maximum energy of the Bevatron. The liquid hydrogen target was 7 feet long and subtended a half-angle of 0.25° at the detector, which is effectively the good-geometry limit. With this geometry, the total measured cross section is $\sigma_T = 33.6 \pm 1.6$ mb. This number shows an appreciable drop from the relative maximum $\sigma_T = 42.4 \pm 1.8$ mb measured at a mean neutron energy of 1.4 Bev at Brookhaven.[2]

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] Atkinson, Hess, Perez-Mendez, and Wallace, Bull. Am. Phys. Soc. Ser. II, 3, 403 (1958).
[2] Coor, Hill, Hornyak, Smith, and Snow, Phys. Rev. 98, 1369 (1955).

KA8. Elastic Scattering of High-Energy Photons by Protons.* R. M. LITTAUER, J. W. DEWIRE, AND M. FELDMAN,† *Cornell University.*—An experiment to measure the scattering process $\gamma + p \rightarrow p + \gamma$ at photon energies of 300 Mev and higher has been undertaken using the bremsstrahlung beam from the Cornell synchrotron. The process is identified by the coincidence detection of the recoil proton in a scintillation counter telescope and the scattered photon in a Čerenkov total absorption counter. Discrimination against π^0 meson production is provided by demanding that the proton have a longer range than can be expected from the π^0 process at the bremsstrahlung maximum. A check is obtained by scanning the angular spread of the photons coincident with the protons in a fixed laboratory solid angle. To date, measurements have been made at an angle of 75° in the center-of-mass system and at photon energies of 325 and 375 Mev. Measurements are being extended to higher energies. Results will be given.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
‡ National Science Foundation Predoctoral Fellow.

KA9. Measurement of the Elastic Scattering of Photons by Protons at 70, 90, and 135° in the Energy Range through Meson Threshold. H. R. KRATZ, J. ROUVINA, AND W. B. JONES, *Research Laboratory, General Electric Company.*—Using the 300-Mev nonferromagnetic electron synchrotron[1] as a source of photons, the differential cross section for elastic scattering of photons by protons at 70, 90, and 135° in the energy range through meson threshold has been measured. A CCl_4 total absorption Čerenkov counter[2] was used as an energy sensitive photon detector and liquid hydrogen as the target. No large divergences from the Powell cross section[3] were observed. The experiment will be described and the results presented and discussed.

[1] W. B. Jones *et al.*, Rev. Sci. Instr. 26, 809 (1955).
[2] Jones, Kratz, and Rouvina, Rev. Sci. Instr. 28, 167 (1957).
[3] J. L. Powell, Phys. Rev. 75, 32 (1949).

KA10. Elastic Scattering of N^{14} by Carbon. C. E. HUNTING, M. L. HALBERT, AND A. ZUCKER, *Oak Ridge National Laboratory.**—The angular distribution of N^{14} nuclei elastically scattered from carbon was measured for scattering angles from 40 to 138 deg (c.m.) at a mean laboratory energy of about 27.5 Mev (12.7 Mev, c.m.). The scattered and recoil particles were detected in separate CsI(Tl) scintillation counters. The output of one counter was displayed on a 20-channel analyzer which was gated by the second counter. The target was a 150 $\mu g/cm^2$ foil of dried graphite suspension, and had an energy thickness of about 1 Mev for 27.5-Mev nitrogen ions at the maximum target angle. The experimental setup will be discussed further (with emphasis on multiple scattering effects), and the results will be presented. Marked structure is evident in the angular distribution. Gross features of the ratio of the observed to the Coulomb differential cross section, with preliminary values of the ratio given in parentheses, are as follows: maxima at 105 deg (0.091) and 132 deg (0.14); minima at 90 deg (0.031) and 118 deg (0.025). Less prominent structure was observed at smaller angles. No pure Coulomb scattering was observed, the ratio at 40 deg being about 0.50.

* Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.

KA11. Interactions of N^{14}, O^{16}, and Ne^{20} with Bi^{209}.* EUGENE GOLDBERG AND H. L. REYNOLDS, *University of California, Livermore.*—The angular distributions of N^{14}, O^{16}, and Ne^{20} elastically scattered by Bi^{209} have been measured at the laboratory energy of approximately 10.2 Mev per nucleon of incident ion. The Berkeley HILAC was employed in a procedure identical to that followed in an earlier study of $C^{12}+Au^{197}$.[1] Nuclear interaction distances, $r_0 - 1.45 \times 10^{-13}$ cm, are in agreement with those from the earlier work. Ilford *D*-1 plates were used for the N^{14} and Ne^{20} exposures, enabling a determination of the total fission cross sections and fission-product angular distributions. Results will be presented.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] E. Goldberg and H. L. Reynolds, Phys. Rev. 112, 1981 (1958).

FRIDAY MORNING AT 9:30

National Bureau of Standards, East Building

(J. W. BEAMS presiding)

Invited Papers

L1. Crystal Growth. NICHOLAS CABRERA, *University of Virginia.* (30 min.)

L2. Phase Determination Directly from X-Ray Intensities in the Crystal-Structure Problem. J. KARLE, *U. S. Naval Research Laboratory.* (30 min.)

L3. Shape of the Earth from Satellite Data. J. O'KEEFE, *NASA.* (30 min.)

L4. Transfer of Vibrational Energy to Translational Energy in Collisions. K. F. HERZFELD, *Catholic University of America.* (30 min.)

FRIDAY MORNING AT 9:30

Room B in Departmental Auditorium

(R. C. BONDELID presiding)

Theory, III: Nuclear

M1. (Abstract withdrawn.)

M2. Three-Body Model of Li^6. P. H. WACKMAN AND N. AUSTERN, *University of Pittsburgh.*—We regard Li^6 as neutron +proton+α particle, and insert variational wave functions for this three-body system into Rayleigh's principle, as in calculations for H^3. A nucleon-α interaction which fits the scattering is used, and the center-of-mass is treated exactly. All the (mutually orthogonal) low lying states may be considered. Assuming the ground state to be pure $(p^2)^3S_1$, initially, and taking a one-term radial wave function, the energy of this state is $E(^3S_1)=-2.11$ Mev, relative to zero energy for three separated particles. The corresponding charge is 2.0×10^{-13} cm. Also using single-term radial functions: $E(^3D_3)=2.2$ Mev, and $E(^3D_2)\approx4.6$ Mev (although no true minimum for this state). The level ordering agrees with experiment. It is interesting that the total kinetic energies in the ^3D and ^3S states are different, but with the effects of the centrifugal stretching in the ^3D states largely compensated by the recoil energy of the α particle in those states. Further calculations with two-term radial functions gave negligible change in the $^3S_1$ energy, but reduced $E(^3D_3)$ to 1.9 Mev and $E(^3D_2)$ to (about) 4.5 Mev.

M3. Effective Tensor Interaction in the N^{14} Ground State.* STAVROS FALLIEROS, MANOJ K. PAL, AND RICHARD A. FERRELL, *University of Maryland.*—In previous work[1] the formation of a state in O^{16} with quantum numbers $J=2+$, $T=0$ from a superposition of one-nucleon excitation was investigated. The effects of the virtual excitation of this state in enhancing electromagnetic transitions in various nuclei around O^{16} was also discussed. This virtual excitation can be shown also to contribute to the effective interaction between the two holes in N^{14}. In particular, there results an induced noncentral force in the N^{14} ground state.[2] It follows that a detailed explanation of the anomalously long C^{14} β-decay lifetime[3] should take into account this additional contribution to the total effective tensor interaction.

* Work supported in part by the U. S. Atomic Energy Commission.

[1] S. Fallieros and R. A. Ferrell, Bull. Am. Phys. Soc. Ser. II, 3, 49 (1958); and (to be published); S. Fallieros, Bull. Am. Phys. Soc. Ser. II, 4, 60 (1959).

[2] The suggestion that an effective tensor force can result from small deformations in the ground state of N^{14} is due to T. H. R. Skyrme (private communication and forthcoming paper in Nuclear Physics).

[3] J. P. Elliott, Phil. Mag. 1, 503 (1956); W. M. Visscher and R. A. Ferrell, Phys. Rev. 107, 781 (1957).

M4. Theory of Inelastic Scattering on C^{14} and N^{14}.* W. T. PINKSTON AND E. K. WARBURTON, *Princeton University.*—The theory of inelastic scattering by direct interaction is applied to C^{14} and N^{14}. The calculations are made in Born approximation with a zero-range transition operator. The cross sections for excitation of levels which arise from the lowest $1p^{10}$ configuration are calculated in intermediate coupling for alpha excitation of N^{14}. Other configurations, in particular $p_{\frac{1}{2}}s_{\frac{1}{2}}$ and $p_{\frac{1}{2}}d_{\frac{3}{2}}$, are treated in jj coupling. A comparison with the Indiana (α,α') data shows that these results are consistent with the following shell model assignments for N^{14} levels, previously suggested by Warburton, Rose, and Hatch: 4.91 $(p_{\frac{1}{2}}s_{\frac{1}{2}}0^-)$, 5.10 $(p_{\frac{1}{2}}d_{\frac{3}{2}}2^-)$, 5.69 $(p_{\frac{1}{2}}s_{\frac{1}{2}}1^-)$, 5.83 $(p_{\frac{1}{2}}d_{\frac{3}{2}}3^-)$. It is suggested that the 6.23-Mev level arises from configurations p^3s^2, p^5d^2, and p^4sd since it is not observed in (α,α^0). Both the 6.44- and the 7.02-Mev levels have (α,α') cross sections consistent with the assignment, $^3D_2(p^{10})$. Similar results will be presented for (p,p') in C^{14} and N^{14}.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

M5. Energy Level Structure of C^{12}.* S. MESHKOV, *University of Pittsburgh.*—An intermediate coupling calculation for C^{12} has been done using a central potential mixture which provides a good fit to the levels of Li^6 and Li^7.[1] The configuration is assumed to be $(1s)^4(1p)^8$. The potential used has $V_W=V_M=0.4$; $V_B=0.2$; $V_H=0$. The splitting between the 0-, 4.44-, and 7.65-Mev levels which have spins 0+, 2+, and 0+, respectively, can be fitted very well. In addition, it is found that the splitting between the two $J=0+$ states does not change rapidly with changing L/K for a fixed a/K. The characteristics of the wave functions for the three states will be discussed.

* Research supported by the National Science Foundation.
[1] S. Meshkov and C. W. Ufford, Phys. Rev. 101, 734 (1956).

M6. Evidence for Shell-Model States in Sc^{41}. J. H. JOHNSON AND C. M. CLASS, *The Rice Institute.*—The states of Sc^{41} are of considerable interest because of the possibilities they present for testing the applicability of the single particle version of the shell model. States in Sc^{41} lying in the interval of excitation energy between 2.2 and 7 Mev have been studied by elastically scattering protons from Ca^{40}, at bombarding energies between 1.3 and 5.5 Mev. The scattered protons were observed at 90° and 150° to the beam by means of a CsI crystal spectrometer. From an analysis of the shapes of the resonances observed for the scattered protons, it was possible to assign the energy and l value of the protons forming 34 states. This analysis was made using the dispersion theory to fit the experimental excitation function. In addition, the total widths Γ for these states were determined and from these the reduced widths (γ^2) were calculated. The reduced widths for states formed by protons of a given l value, when plotted as a function of the energy of the states, go through a definite maximum which suggests the influence of the single particle levels expected in the shell model. This effect is clearly apparent for four groups of states having $l=1\,(p_{1/2})$, $l=2\,(d_{5/2})$, $l=3\,(f_{5/2})$, and $l=4\,(g_{9/2})$. The mean values of the excitation energy in Sc^{41} of these groups are respectively 4, 6, 6.4, and 5.5 Mev.

M7. Energy Levels of Pb^{205}.* WILLIAM W. TRUE, *Princeton University.*—An intermediate coupling calculation of the energy levels of Pb^{205} has been done. It was found that it is necessary to include weak collective coupling to the core in order to get a reasonable fit to the experimental data. The parameters are the same as those used in Pb^{209}.[1] The experimental data on Pb^{205} will be discussed in connection with these theoretical calculations. In particular, an explanation for the isomeric level found[2] in Pb^{205} will be given.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] W. W. True and K. W. Ford, Phys. Rev. 109, 1675 (1958).
[2] S. H. Vegors and R. L. Heath, Bull. Am. Phys. Soc. Ser. II, 3, 209 (1958).

M8. Pairing Energies in Spheroidal Nuclei. A. A. ROSS, *Oxford University.*—An attempt has been made to calculate pairing energies in the region $150<A<190$, where nuclei exhibit rotational spectra. On the basis of the spherical shell-model neutron pairing energies in this region would be attributed to pairing principally in the $1i_{13/2}$ level and sometimes in the $1h_{9/2}$ level. Using a short-range (δ function) interaction of a strength such that the experimentally observed pairing energy for the $3p_{1/2}$ level in Pb^{208} is fitted, this predicts for either a square well, harmonic oscillator or Woods-Saxon potential pairing energies of the order 2 Mev. In the opposite extreme for the collective model, with only particles paired in the same level interacting, the prediction is of the order 0.4–0.5 Mev. Thus the first is too large and the second too small to fit experiment. However, in the collective model the off-diagonal matrix elements between pairs are not negligible. It is found that their effect is critically dependent on the relative size of the off-diagonal matrix elements and the pair spacings; and in the first approximation linearly dependent on the number of excited pair levels allowed to interact. With reasonable assumptions the pairing energy and the "energy gap" are both predicted to be about 1 Mev.

M9. Moments of Inertia of Even-Even Nuclei in the Rare Earth Region.* JAMES J. GRIFFIN AND MARVIN RICH, *Los Alamos Scientific Laboratory.*—Moments of inertia are calculated for even-even nuclei in the rare earth region using the "cranking model" formula[1] and the deformed wave functions of Nilsson.[2] The cranking model formula is modified by increasing the magnitude of each energy denominator[3] by a "pairing energy" calculated for each single particle state with an attractive delta function interaction. The coefficient of this interaction is adjusted to give approximately the observed magnitude of the moments in this region. The calculated moments for various isotopes are compared with the values inferred from experimental data on the energies of 2+ rotational states. Modifications of the level ordering which are indicated by analyses of odd-A spectra[4] in this region are found also to improve the agreement between these calculations and the experimental data.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] D. R. Inglis, Phys. Rev. 96, 1059 (1954).
[2] S. G. Nilsson, Kgl. Danske Videns. Rab. Selskak. Mat.-fys. Medd. 29, No. 16 (1955).
[3] A. Bohr and B. R. Mottelson, Kgl. Danske Videns. Rab. Selskak. Mat.-fys. Medd. 30, No. 1 (1956).
[4] B. R. Mottelson and S. G. Nilsson, "The intrinsic states of odd-A nuclei having ellipsoidal equilibrium shape" (to be published).

M10. Effect of Residual Interactions on the Ground States of Nuclei. IRA L. KARP, *Boeing Airplane Company.*—The machine computed effect of residual delta function interactions on the shape and ground-state physical properties of nuclei has been compared to recent calculations, with qualitative agreement secured on deformation trends and state splittings. The Hamiltonian, which is that of Nilsson with added delta function forces of variable strength, is diagonalized starting from two representations: the Nilsson representation (for which the delta function is the perturbation), and the independent pair representation (for which $1\cdot s$ and 1^2 terms are the perturbations). The use of the independent pair approximation is justified in part by favorable comparison of results with those of exact diagonalization of the many-particle Hamiltonian, in three cases. The extensive use of the Tamm Dancoff approximation is confirmed by the convergence of the eigenvalues with increasing matrix size.

M11. Simplified Intermediate Coupling Shell Model by Variational Treatment.* D. S. KOLTUN, C. A. LEVINSON, AND H. A. HILL, *Princeton University.*—Redlich[1] and Elliott[2] have pointed out that the wave functions of the intermediate coupling shell model are closely related to those obtained in the Griffin Wheeler[3] treatment of the collective model. Using an intrinsic wave function in the form of a determinant of one-particle wave functions of mixed j, nuclear wave functions are obtained by projecting out states of total angular momentum. Variation of the parameters which mix different j's, to minimize the interaction energies yields results which may be compared to those of the intermediate coupling model. In particular, we have calculated energies for the ground-state band of Be^9 and find close correspondence with those calculated by Kurath[4] and French *et al.*[5] for a range of values of a/K.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] M. Redlich, Phys. Rev. 110, 468 (1958).
[2] J. P. Elliott, Proc. Roy. Soc. (London) A245, 128, 562 (1958).
[3] J. Griffin and J. A. Wheeler, Phys. Rev. 108, 311 (1957).
[4] D. Kurath, Phys. Rev. 101, 216 (1956).
[5] French, Halbert, and Pandya, Phys. Rev. 99, 1387 (1955).

M12. Variational Treatment in the s-d Shell.* SHIGUEO WATANABE,† C. A. LEVINSON, AND H. A. HILL, *Princeton University.*—The variational method described in the preceding abstract was applied to the calculation of the low lying states and energy spacings of F^{19} and Ne^{20}. The interaction employed by Elliott and Flowers[1] was used and the results for F^{19} were compared with their work. The spacings of the low lying $T=\frac{1}{2}$ states agreed to within 0.2 Mev. The same interaction was used in a calculation of the Ne^{20} low lying levels and the spacing of the first two excited states agree with experiment. Corrections by admixture of two determinants will be discussed.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
† Fellow of the National Research Council of Brazil.
[1] J. P. Elliott and B. H. Flowers, Proc. Roy. Soc. (London) **A229**, 536 (1955).

M13. Axially Symmetric States in the Shell Model.* M. J. ENGLEFIELD, *Ohio State University* (introduced by A. M. Sessler).—In the collective model, observed properties of many nuclei have been predicted from wave functions representing states with an axis of symmetry. This paper discusses whether such states can exist in the independent particle model. A sufficient condition for the stationary states of a system to be axially symmetric is that the Hamiltonian $T+V$ commutes with an angular momentum component J_s along a principal axis. An expression for the commutator of J_s and the kinetic energy T of a system of particles has been obtained, and the possibility considered of choosing a potential V so that $J_sV-VJ_s=TJ_s-J_sT$. This condition cannot be satisfied if V is a scalar function of the spins and coordinates. The commutators were obtained between J_s and the components, along both space-fixed and principal axes, of symmetric operators linear in the momenta. For a shell-model Hamiltonian of the form $H=\Sigma_i H_i$, where $H_i=T_i+V_i$ is a one-body Hamiltonain, the results indicate that the above criterion cannot be satisfied if V_i is a scalar, linear in the components of $\mathbf{p}_i$.

* Supported by the National Science Foundation.

M14. Approximate Calculation of the Reaction Matrix in Nuclear Matter.* STEVEN A. MOSZKOWSKI, *University of California.*—In order to calculate various properties of nuclear matter, it may be useful to break up the nucleon-nucleon interaction into short- and long-range parts, v_s and v_l. Denote the reaction matrix for free particle scattering by v_s alone as t_s^0. Then the complete reaction matrix in nuclear matter can be expanded in powers of t_s^0 and v_l;

$$t=t_s^0+v_l+t_s^0\left(\frac{1}{e}-\frac{1}{e_0}\right)t_s^0+2v_l\frac{1}{e}t_s^0+v_l\frac{1}{e}v_l\cdots,$$

where e_0 and e denote appropriate energy denominators for free particles and in nuclear matter. Consider, for example, the singlet central even-state interaction. If the division between v_s and v_l is taken at about 1 fermi (but not at the radius $\sim$0.4 fermi of the repulsive core), then the terms of second order in t_s^0 and v_l, averaged over the Fermi sea, are relatively small compared to the first-order terms. Under these conditions, it seems plausible that terms of third- and higher order can be neglected, to a good approximation.

* This work is supported in part by the Office of Ordnance Research.

M15. On Superheavy Nuclei.* E. E. SALPETER, *Cornell University.*—According to the nuclear symmetry energy obtained by a simple extrapolation of the semiempirical mass formula, the upper limit[1] on the atomic number of stable superheavy nuclei is a few hundred. It is however possible, although unlikely, that even large drops of all-neutron matter are just barely stable. Assuming such stability the low density of protons and electrons inside and on the surface of such a drop, and the resulting negative contribution to surface tension, is evaluated. The nuclear transformations resulting if an ionized Fe gas, say, is compressed to high density, as well as possible although unlikely applications to astrophysics, will be discussed.

* Supported in part by joint contract of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] F. G. Werner and J. A. Wheller, Phys. Rev. **109**, 126 (1958).

FRIDAY MORNING AT 9:45

(Departmental Auditorium)

(G. E. UHLENBECK presiding)

Lecture by the First Recipient of the Dannie Heineman Prize for Mathematical Physics

MA1. The Decays of Strange Particles. MURRAY GELL-MANN, *California Institute of Technology.* (45 min.)

Lectures in Memory of Ernest Orlando Lawrence

MA2–3. The History of the Cyclotron. M. STANLEY LIVINGSTON, *M.I.T.*, and then E. M. MCMILLAN, *University of California, Berkeley.* (1 hr, 15 min for the two.)

FRIDAY AFTERNOON AT 2:00

Departmental Auditorium

(E. M. MCMILLAN presiding)

Symposium on Accelerators of the Future

N1. The Brookhaven Alternating Gradient Synchrotron. G. K. GREEN, *Brookhaven National Laboratory.* (30 min.)

N2. The MURA Accelerator Programme. K. R. SYMON, *Midwestern Universities Research Association.* (30 min.)

N3. The Planned Stanford Two-Mile Linear Electron Accelerator. W. K. H. PANOFSKY, *Stanford University.* (30 min.)

N4. Progress on the Cambridge Electron Accelerator. M. STANLEY LIVINGSTON, *M.I.T.* (30 min.)

FRIDAY AFTERNOON AT 1:45

Willard, Congressional Room

(H. W. KOCH presiding)

Fast Neutrons

NA1. Neutron Form Factors from High-Energy Electron-Deuteron Scattering.* S. SOBOTTKA AND R. HOFSTADTER, *Stanford University.*—The inelastic electron-deuteron scattering cross section has been measured from 300 to 650 Mev in order to improve[1] the determination of F_{2n} and to place rough limits on F_{1n}. The data were analyzed in terms of the impulse approximation.[2] Rough calculations by Jankus[3] and Durand[4] indicate that corrections due to final-state interactions may be important, so the analysis in terms of neutron form factors must remain incomplete until more satisfactory calculations appear. If these corrections are neglected and if F_{1n} is assumed to be zero, F_{2n}^2 appears to be about 25% larger than the proton form-factor[1] at the smallest values of q^2 measured (2.65 to 5), the difference decreasing to zero at the largest values of q^2 measured (10 to 15.1). The final state interaction correction would accentuate this difference. For $5.1 < q^2 < 12.8\, f^{-2}$, data were taken both at 135° and at a small angle (60° to 90°) for the same q. The results indicate that $-2.5 < (F_{1n}/F_{2n}) < 0.5$ for these q values.

* Supported by the joint program of the Office of Naval Research, the U. S. Atomic Energy Commission, and the Air Force Office of Scientific Research.

[1] Hofstadter, Bumiller, and Yearian, Revs. Modern Phys. **30**, 482 (1958).
[2] A. Goldberg, Phys. Rev. **112**, 618 (1958).
[3] V. Z. Jankus, Phys. Rev. **102**, 1586 (1956).
[4] L. Durand, III (private communication).

NA2. Neutrons from π^- Capture in Hydrogen: The Mass or Masses of the π^0.* W. SELOVE, K. LANDE, M. GETTNER, L. HOLLOWAY, D. KRAUS, AND E. LEBOY, *University of Pennsylvania,* AND R. SIEGEL, *Carnegie Institute of Technology.*—Neutrons produced by π^- mesons stopping in hydrogen were detected with a time-of-flight technique. A preliminary measurement shows the clearly defined 8-Mev group from radiative capture, and peaked structure in the vicinity of the 0.4-Mev group expected from the nonradiative capture. Results of further analysis of the data will be given.

* Supported by the U. S. Atomic Energy Commission.

NA3. Photoneutrons from Lithium and Nitrogen.* P. A. FLOURNOY, R. S. TICKLE, R. W. FAST, AND W. D. WHITEHEAD, *University of Virginia.*—The cross section for photoneutron production has been determined for lithium and nitrogen as a function of x-ray energy from 11 to 55 Mev using the bremsstrahlung from the University of Virginia synchrotron. The neutrons were detected in a Halpern type counter consiting of six BF3 counters in a moderator which was gated to count between beam pulses. The beam intensity was monitored with a NBS-type thick-walled transmission ion chamber. 1 1¼-in.-diam stainless steel tube filled with the gas to 2100 lb/cm² was used as a target for the nitrogen; the lithium target was natural metallic lithium encased in a thin plastic cylinder. The data were taken at 1-Mev intervals in the bombarding energy, and the cross sections were extracted from the yield curve using the Leiss-Penfold matrices. The integrated cross sections determined were Liσ int(11–60 Mev)0.090 Mev barn; N_2, σ int(13–55 Mev)0.165 Mev barn.

* Supported by the U. S. Air Force Office of Scientific Research.

NA4. Yield of Fast Photoneutrons from Tantalum and Gold.* L. B. AULL, G. C. REINHARDT, AND W. D. WHITEHEAD, *University of Virginia.*—The yield of neutrons from tantalum and gold with energies above the $Si^{28}(n,p)Al^{28}$ threshold has been determined as a function of the maximum bremsstrahlung energy from 18 to 64 Mev at 1-Mev intervals using the University of Virginia synchrotron. Silicon powder packed between two thin-walled concentric plastic cylinders was used as a neutron detection. One-in.-diam cylindrical samples of the metals were mounted axially with the beam and the 2-in.-diam detector was mounted coaxially with the sample. The residual Al^{28} activity was measured with a manifold of 3 Geiger counters. The beam intensity was monitored with the Cu^{62} activity from the $Cu^{63}(\gamma,n)Cu^{62}$ reaction in thin copper disks. The normalized yield functions for the gold and tantalum are identical within the counting statistics of about 5% and both increase at higher energies, but this might be due to the assumptions concerning the fast neutron spectrum. The integrated cross section to 64 Mev is 0.750 Mev barns and at 30 Mev is about 5% of the total neutron integrated cross section.[1]

* Supported by the U. S. Air Force Office of Scientific Research.
[1] L. W. Jones and K. M. Terwilliger, Phys. Rev. **91**, 699 (1953).

NA5. Elastic Scattering of Neutrons from Ag and In. P. R. MALMBERG AND S. C. SNOWDON,* *U. S. Naval Research Laboratory.*—The differential cross sections for the elastic scattering of 6.7-Mev neutrons from silver and indium have been measured for 40 angles between 4° and 158°. A ring geometry was used with D-D neutrons and a detector consisting of six separated pieces of plastic scintillator placed directly against the end of a photomultiplier. The resultant data were analyzed as a function of detector pulse height to determine the extent of discrimination against inelastically scattered neutrons.

* Permanent address: Bartol Research Foundation.

NA6. Angular Distributions of Neutrons Elastically Scattered by Light Elements.* S. BERKO,† B. C. GROSECLOSE,‡ R. F. STETSON,‡ and W. W. WALKER, *University of Virginia.*—Angular distributions of 15-Mev neutrons elastically scattered by O and Mg have been obtained up to 130° (lab). An angular distribution was also done at 14 Mev for Mg to investigate possible anomalous energy variations in the differential cross section. A ZrT target was used to produce neutrons by means of the $T(d,n)He^4$ reaction. The neutron beam was electronically collimated by time-of-flight techniques and the data recorded on a 20-channel analyzer, gated by the n-α coincidences. The data will be compared with the results of optical model calculations.

* Supported jointly by the U. S. Army Office of Ordnance Research and the U. S. Atomic Energy Commission.
† A. P. Sloan Research Fellow on leave 1958–1959 at Institute for Theoretical Physics, Copenhagen.
‡ Recipient of Predoctoral Fellowship from the Southern Fellowships Fund.

NA7. Elastic Scattering of 24-Mev Neutrons from Aluminum, Iron, Tin, and Bismuth.* T. P. STUART, JOHN D. ANDERSON, C. C. GARDNER, J. W. MCCLURE, M. P. NAKADA, AND C. WONG, *University of California, Livermore.*—Preliminary data for elastic scattering of 24-Mev neutrons from aluminum, iron, tin, and bismuth have been obtained for angles between 15° and 90° in 5° steps. Cylindrical scatterers, half a total mean free path in diam, 20 cm in length, and located 110 cm from a tritium gas target, were bombarded with neutrons from the d-t reaction. Depending on angle and

scatterer, this geometry afforded an angular resolution of from ±4° to ±2°, with the poorer resolution occurring at smaller angles. Neutrons were detected in a plastic scintillator placed on a 76-cm radius from the scatterers and biased at about 23, 20, and 17 Mev. Direct neutrons were attenuated with about 1 m of Fe absorber. Counting statistics for the 20-Mev bias data vary between about 3% and 35%, depending on the scatterer and angle. The preliminary data (for which absorption and multiple scattering corrections are now in progress on the UNIVAC) are in reasonable agreement with optical model calculations of Bjorklund and Fernbach.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

NA8. Neutron Total Cross Sections in the 17- to 30-Mev Range.* J. P. STOERING, J. M. PETERSON, AND A. BRATENAHL, *University of California, Livermore and Berkeley.*—The neutron total cross sections of about 40 elements and isotopes were measured at several energies between 17 and 30 Mev using mono-energetic neutrons produced by the Livermore variable-energy cyclotron through the $T(d,n)He^4$ reaction. The effects of beam contamination and low-energy "breakup" neutrons were evaluated through time-of-flight measurements and were kept small by suitably high bias on the plastic scintillator detector. The data in this energy region have been sparse heretofore. Where comparisons with previous data have been possible, there is substantial agreement. When plotted *versus* energy and mass number, the data form a smooth cross-section surface which joins on smoothly to the data at lower energies.[1] The data seem in good agreement with the predictions of the optical model of Bjorklund and Fernbach.[2]

* Work performed under auspices of the U. S. Atomic Energy Commission.
[1] Bratenahl, Peterson, and Stoering, Phys. Rev. 110, 927 (1958).
[2] F. Bjorklund and S. Fernbach, Phys. Rev. 109, 1295 (1958).

NA9. Neutrons from the Triton Bombardment of Li^6 and Li^7.* FAY AJZENBERG-SELOVE, *Haverford College,* AND NELSON JARMIE AND EUGENE HADDAD, *Los Alamos Scientific Laboratory.*—Thin, highly enriched targets[1] of Li^6 and Li^7 were bombarded with 1.90-Mev tritons from an electrostatic accelerator at the Los Alamos Laboratory. Ilford C-2 emulsions, 400 μ thick, placed at 10 angles (0°–135°) to the incident beam were used as neutron detectors and are being searched to give the neutron spectra from $Li^6(t,n)Be^8$ and $Li^7(t,n)Be^9$ reactions. Preliminary data will be presented on levels of Be^8 with $E_x \lesssim 13$ Mev and on levels of Be^9 with $E_x \lesssim 8$ Mev. Neutrons from carbon and oxygen contamination preclude observation of higher states. At 120°, the contributions from the $Li^6(t,n)2He^4$, $Li^7(t,2n)2He^4$, and $Li^7(t,n2)Be^8$ reactions are very small relative to those of the two-body reactions.

* Research supported by the National Science Foundation and by the U. S. Atomic Energy Commission.
[1] Li^7 target kindly supplied by Dr. M. L. Smith of the Atomic Energy Research Establishment, Harwell, England.

NA10. Spectrum of Neutrons from 14-Mev Neutrons Incident on Uranium. R. L. CLARKE, *Atomic Energy of Canada Ltd.*—The spectrum of neutrons resulting from 14-Mev neutrons incident on natural uranium has been observed from 2 to 10 Mev. Observations were made at 90° to the incident neutrons by means of a time-of-flight system. Absolute cross sections were obtained by comparison with the known cross section for 14-Mev elastic scattering from carbon.[1] The data of Zamiatnin *et al.*[2] on the shape of the spectrum from 0.2 to 5 Mev are in qualitative agreement with the present work. The combined data can be fitted from nearly 0 to 6 Mev with a sum of evaporation and fission neutrons having a spectrum similar to that found in thermal fission. The evaporation portion of the spectrum above 1 Mev appears to have a temperature of 0.66±0.07 Mev. Above 6 Mev there is an excess of neutrons over the evaporation plus fission neutrons, which amounts to about a factor of 4 at 8 Mev. An additional experiment has shown that these excess neutrons are strongly peaked forward.

[1] Nakada *et al.*, Phys. Rev. 110, 1439 (1958).
[2] Zamiatnin, Sufina, Gutnikova, and Ivanova, Atomic Energy (U.S.S.R.) (English Translation) 2, 337 (1957); Vasilev, Zamiatnin, Toropov, and Fomushkin, *ibid.* 2, 542 (1957).

NA11. Inelastic Scattering of 14-Mev Neutrons by Magnesium. W. G. CROSS AND R. L. CLARKE, *Atomic Energy of Canada Ltd.*—The angular distribution of neutrons from the reaction $Mg^{24}(n,n')Mg^{24}$, $Q=-1.37$ Mev, was measured from 30° to 150°. A beam of 14.1-Mev neutrons from the *T-D* reaction, defined by the associated α particles, passed through a sample 2 cm thick. The energy of the scattered neutrons was determined from their time of flight over a 2-m flight path. The neutron detector was a plastic scintillator biased at 8 Mev and shielded from direct neutrons. The full width at half-maximum for elastically scattered neutrons was 2 mμsec. Absolute values of differential cross sections were determined by comparison with the elastic distribution.[1] The integrated cross section is of the order of one-tenth of the total inelastic cross section. The differential cross section has the same general shape as that of 18-Mev protons scattered inelastically from the same level[2] but differs in detail in that the first strong minimum of the neutron data occurs near 90°. The angular distribution indicates that the principal reaction mechanism is a direct interaction. Neutrons scattered from levels at 4.12 and 4.24 Mev are less than one-quarter as numerous as those from the 1.37-Mev level.

[1] W. G. Cross and R. G. Jarvis, Phys. Rev. 99, 621A (1955); Berko, Whitehead, and Groseclose, Nuclear Phys. (to be published).
[2] P. C. Gugelot and P. R. Phillips, Phys. Rev. 101, 1014 (1956).

NA12. Energy Distribution of Fast Neutrons Scattered Inelastically by Indium, Antimony, Niobium, Iodine, and Thallium.* D. B. THOMSON AND L. CRANBERG,† *Los Alamos Scientific Laboratory.*—The energy distributions of fast neutrons scattered inelastically by In, Sb, Nb, I, and Tl have been observed at 90° for an incident neutron energy of 4.0 Mev. The pulsed-beam time-of-flight technique was used to measure the neutron energies. The spectra of inelastically scattered neutrons could be observed with reasonable accuracy in the range of 0.5 to 3.0 Mev. Preliminary attempts have been made to fit the data using the nuclear temperature concept.[1] Plots of $\ln(1/E)dN/dE$ *vs* E indicate a reasonably linear fit in the energy range of about 0.6 to 2.0 Mev, then an excess of neutrons for energies above 2.0 Mev. The temperatures indicated by these fits are:

Element	In	Sb	I	Tl	Nb
Temperature (Mev)	0.38±0.04	0.39±0.04	0.39±0.04	0.7±0.1	0.33±0.04

Similar data have been taken for an incident energy of 7.0 Mev. Results obtained at this energy, as well as results of further analysis of the 4.0-Mev data, will be presented.

* Work was done under the auspices of the U. S. Atomic Energy Commission.
† Visiting Professor at Case Institute of Technology, on leave from Los Alamos Scientific Laboratory.
[1] Hans Bethe and Philip Morrison, *Elementary Nuclear Theory* (John Wiley and Sons, Inc., New York, 1956), second edition.

NA13. Gamma Rays from Inelastic Neutron Scattering in Ti, Cr, Fe, Ni, and Zn.* N. NATH, S. S. MALIK, M. A. ROTHMAN, AND D. M. VAN PATTER, *Bartol Research Foundation.*—Gamma-ray spectra have been observed from ring scatterers of Ti, Cr, Fe, Ni, and Zn for $E_n=1.45$ to 2.7 Mev. Gamma rays of the following energies in Mev (accuracy 1 to 2%) have been assigned to specific isotopes from a knowledge of their approximate thresholds and energy level schemes: Ti^{46}0.89; Ti^{48}0.99, 1.32, 1.48; Ti^{49}1.37; Ti^{50}1.58. Cr^{50}0.78;

Cr^{52}0.94, 1.43; Cr^{53}0.56, 1.01, 1.29; Cr^{54}0.84. Fe^{54}1.41; Fe^{56} 0.845, 1.24. Ni^{58}1.45; Ni^{60}0.82, 0.97, 1.33, 2.15. $Zn^{64, 66, 68}$ (all composite groups) 0.82, 1.01, 1.30, 1.85. Measurements of the yields of the γ rays from the first two levels of eight of the even-even nuclei studied lead to estimates of the ratio of the (n,n') cross sections for the first two levels of these nuclei. This study indicates that the measurement of this ratio near threshold makes it possible to distinguish between 2+ and 4+ spin assignments for the second level of nuclei in this mass region,[1] and leads to an assignment of 2+ for the second level of $Zn^{64, 66, 68}$. The γ-ray branching ratios measured for the second levels of Ni^{60} and $Zn^{64, 66, 68}$ are in disagreement with some of the recent results from radioactive decay studies.[2]

* Assisted by the U. S. Atomic Energy Commission.
[1] Van Patter, Rothman, Nath, Malik, and Mandeville, Bull. Am. Phys. Soc. Ser. II, 4, 32 (1958).
[2] Levine, Frauenfelder, and Rossi, Z. Physik 151, 241 (1958); D. J. Horen (to be published).

NA14. Gamma Rays from Inelastic Neutron Scattering in Ge, Se, and Mo.* S. S. MALIK, C. E. MANDEVILLE, N. NATH, M. A. ROTHMAN, AND D. M. VAN PATTER, *Bartol Research Foundation.*—As part of a survey of even Z nuclei,[1] de-excitation of energy levels in Ge, Se, and Mo have been studied by inelastic neutron scattering for neutron energies from 1.0 to 2.7 Mev. Results obtained concerning the assignments of the γ rays to levels in particular isotopes will be discussed. The γ-ray energies in Mev (accuracy 1–2%) are summarized here. Numbers in parenthesis indicate somewhat uncertain assignments. Ge^{70}: 1.04; Ge^{72}: 0.84, (0.90), 1.48; Ge^{74}: 0.60, 1.22, 2.24; Ge^{76}: 0.55; Ge: 1.12, 1.36, 1.73, 1.99. Se^{76}: 0.57, 1.22; Se^{78}: 0.62, 1.31, (1.98); Se^{80}: 0.66, 0.80, 1.05, 1.46; Se: 0.90, 1.13, 1.78. The experimentally observed ratio for the relative cross sections of the cascade to the cross-over transition for the 1.46-Mev second level in Se^{80} was found to be 1.3±0.4. Results obtained in the study of Mo will also be presented.

* Assisted by the U. S. Atomic Energy Commission.
[1] Van Patter, Rothman, Nath, Malik, and Mandeville, Bull. Am. Phys. Soc. Ser. II, 4, 32 (1958).

NA15. Neutron Transfer Functions. LYLE B. BORST AND CHARLES M. NEWSTEAD, *New York University, University Heights.*—The success of Convergatron neutron amplifiers will depend upon the asymmetry of the transfer functions between stages. Experiments have been directed to achieving efficient forward transfer to the next succeeding stage while inhibiting backward transfer from that stage. The study of highly asymmetric moderators demonstrates the feasibility of a forward-to-backward transmission ratio of greater than 4 to 1 with reasonable forward transmission. The characteristics of a 2-stage amplifier will be discussed.

FRIDAY AFTERNOON AT 1:45

Willard, Grand Ballroom

(A. V. ASTIN presiding)

Invited Papers

P1. Potentialities of Nuclear Propulsion for Space Flight. R. E. SCHREIBER, *Los Alamos Scientific Laboratory.* (30 min.)

P2. On the Production of Polarized Proton Beams. L. MADANSKY, *The Johns Hopkins University.* (30 min.)

P3. Reactions $H^3(\alpha,\gamma)Li^7$ and $He^3(\alpha,\gamma)Be^7$. H. D. HOLMGREN, *U. S. Naval Research Laboratory.* (30 min.)

P4. Experimental Studies of the Energy Levels of N^{15} and O^{15}. D. F. HEBBARD, *California Institute of Technology.* (30 min.)

FRIDAY AFTERNOON AT 1:45

Commerce Auditorium

(S. MILLMAN presiding)

Magnetic Resonance, II

PA1. Optical Orientation of N^{15} Atoms.* N. KNABLE, W. W. HOLLOWAY, JR., AND R. NOVICK, *University of Illinois.* The hyperfine structure of the ground state of atomic nitrogen 15 has been determined by the method of optical orientation. The experimental method and equipment are essentially the same as that described previously[1] in the case of N^{14}. The value obtained for the zero field splitting is 29.2910±0.0003 Mc/sec. The stated uncertainty is equal to three times the probable error and is intended to allow for possible systematic errors that are still being investigated. The line widths are limited by field inhomogeneities to 1.0 kc/sec. The N^{14}-N^{15} hyperfine structure anomaly, δ, has been found to be $\delta=(9.8\pm0.7)\times10^{-4}$, where $\delta=1-(a^{15}/a^{14})(\mu^{14}I^{15}/\mu^{15}I^{14})$; a^{14} and a^{15} are the hyperfine structure interaction constants for N^{14} and N^{15}, respectively. The uncertainty in δ arises almost entirely from the uncertainty in the nuclear moment ratio.[2]

* Works supported in part by the National Science Foundation and the Joint Program of the U. S. Atomic Energy Commission and the Office Naval Research.
[1] W. W. Holloway, Jr., and R. Novick, Phys. Rev. Letters 1, 367 (1958).
[2] W. G. Proctor and F. C. Yu, Phys. Rev. 81, 20 (1951).

PA2. Spin Relaxation of Optically Aligned Rubidium Vapor.* W. FRANZEN, *Arthur D. Little, Inc.*—The relaxation time of rubidium vapor, aligned by optical pumping with

circularly polarized resonance radiation containing the 7940-A line only, has been studied by a new method. The pumping radiation is suddenly shut off completely by a mechanical shutter and turned on again after a measured time interval. Since the state of alignment of the vapor and its optical transparency are related to each other, the vapor becomes more opaque when it is allowed to relax in the dark, and the increase in opaqueness as a function of time is a direct measure of the relaxation time. A relaxation time of 80 msec as well as a large degree of alignment were observed in a closed off evacuated cell having glass walls lined with a thin film of tetracontane ($C_{40}H_{82}$). A number of other organic wall coatings were also investigated. Cross sections for disorientation collisions have been measured in neon, argon, krypton, and xenon by studying the relaxation time as a function of gas pressure in lined and unlined cells. Ambipolar diffusion coefficients for rubidium diffusing through neon and argon were also measured. The longest observed relaxation time of approximately 0.4 sec was observed in a tetracontane-lined cell filled with 3 cm Hg of neon.

* Work supported by the U. S. Army Signal Corps.

PA3. Ultracentrifuge for the Measurement of Nuclear Resonance Fluorescence.* F. J. WILHELM, B. I. DEUTCH, AND F. R. METZGER, *Bartol Research Foundation.*—Gamma rays from the de-excitation of atomic nuclei will cause resonance fluorescence in identical nuclei only if one compensates for the recoil energy loss in the emission and absorption processes. One way of achieving the necessary Doppler shift, is to use the high peripheral speeds of ultra centrifuges.[1] A design by Beams[2] of an air driven ultra centrifuge was adapted to the special requirements of resonance fluorescence experiments. With 5-in. diam Al rotors especially shaped for minimum gamma ray absorption, sources with volumes up to 0.01 ml can be used. The electronic equipment is gated so that counts are accepted only when the gamma rays striking the scatterer are essentially emitted in a tangential direction. The advantages of the design are high signal to noise ratio, simplicity of operation, and the small size of the scatterers.

* Supported by a grant from the National Science Foundation.
[1] P. B. Moon, Proc. Phys. Soc. (London) **A64**, 76 (1951).
[2] Beams, Linke, and Sommer, Rev. Sci. Instr. **9**, 248 (1938).

PA4. Nuclear Resonance Fluorescence from the 279-Kev Level of Tl^{203} with an Ultracentrifuge.* B. I. DEUTCH, F. J. WILHELM, AND F. R. METZGER, *Bartol Research Foundation.*—Using a 5-in. Al rotor in the air driven ultracentrifuge described at these meetings, a Hg^{202} source of about 10 Mc and with a specific activity of about 1 Mc/mg was rotated in a vacuum to a maximum velocity of 470 meters/sec. For the geometry used, this maximum source velocity gives rise to a Doppler shift of the emission line which compensates for the recoil energy losses. Nuclear resonance fluorescence from Tl^{203} was measured at this and lower velocities in a scattering experiment. The velocity dependence of the resonance cross section agreed within the experimental accuracy with that expected for a source and scatterer at a temperature of 300° absolute under the assumption of "free recoil."[1] From preliminary results of the magnitude of the resonance effect, assuming a total conversion coefficient of $\alpha_T = 0.225$ and an $E2/M1$ mixture of 2.25,[2] a mean life of $\tau_\gamma = (5.5 \pm 0.7) \times 10^{-10}$ sec was calculated.

* Supported by a grant from the National Science Foundation.
[1] W. E. Lamb, Phys. Rev. **55**, 190 (1939).
[2] F. K. McGowan and P. H. Stelson, Phys. Rev. **109**, 901 (1958).

PA5. Resonance Spectrum of a Paramagnetic Impurity in Topaz.* J. E. GEUSIC† AND DUDLEY WILLIAMS, *The Ohio State University.*—The paramagnetic resonance spectrum of a single crystal of topaz $(Al\,F)_2\,SiO_4$ containing Fe and Cr as impurities has been investigated at X band. At present the paramagnetic resonance spectra observed cannot be ascribed to either Cr or Fe ions in the lattice. However from the symmetry properties of the resonance spectra observed as the crystal is rotated with respect to the magnetic field and from hyperfine structure which is present, the paramagnetic center is identified as occupying Al sites in the topaz lattice.

* Work supported in part by the Office of Scientific Research, Air Research and Development Command.
† Now at Bell Telephone Laboratories.

PA6. Electron Spin Resonance in a γ-Irradiated Single Crystal of Alanine.* ICHIRO MIYAGAWA AND WALTER GORDY, *Duke University.*—We have extended the earlier electron spin resonance measurements[1] on γ-irradiated single crystals of alanine and have made a tentative analysis of the results based on the assumption that the patterns arise from free radicals of the form CH_3-CH-X, in which the CH_3 protons have isotropic and equivalent coupling with the electron spin, the CH proton has an isotropic Fermi-type component plus an anisotropic, dipole-dipole component, and the X group has no coupling nuclei. Measurements were made on *d*- and *l*-alanine for which the crystal symmetry[2] is $D_2{}^4{}_2{}_1{}_2{}_1{}_2{}_1$. There are 4 molecules in unit cell; but for orientations of the static field parallel to the crystallographic axes, the free radicals in the four orientations are magnetically equivalent. For [001] a quintet pattern with intensity ratios 1:4:6:4:1 is observed. For [100] or [010] a pair of superimposed quartets is observed, which indicates for this orientation one proton has a coupling different from the other three. Second order effects which depend on the observation frequency were also observed.

* This research was supported by the Office of Ordnance Research, Department of the Army.
[1] A. Van Roggen, L. Van Roggen, and Gordy, Bull. Am. Phys. Soc. Ser. II, **1**, 266 (1956).
[2] J. D. Bernal, Z. Krist. **A78**, 362 (1931).

PA7. Paramagnetic Resonance Spectra of *V* Centers in Irradiated $NaClO_3$.* T. E. HASTY, W. B. ARD, JR., AND W. G. MOULTON, *University of Alabama.*—From the hyperfine structure of the paramagnetic resonance absorption spectra of a single crystal of $NaClO_3$ it is concluded that the V center produced by x-irradiation is a radical containing one chlorine nucleus. This center is probably produced by the stripping of an electron from a ClO_3^- ion and the subsequent breaking up of the ClO_3 into ClO and O_2. The O_2 diffuse into the lattice and the ClO remains in the position of the original ClO_3^- ion and retains the same axis symmetry as the ion. The *s*-state and *p*-state contributions to the hyperfine structure and the direction of the axis of quantization are determined from an analysis of the orientation dependence of the spectra.

* This work supported by the Office of Ordnance Research.

PA8. Paramagnetic Resonance in Irradiated Marlex-50 Polyethylene at Room Temperature. R. S. POWELL, E. J. LAWTON, AND J. S. BALWIT, *General Electric Company.*—Electron spin resonance in Marlex-50 irradiated with 800-KVP electrons to a dose of 40 megaroentgens has been observed at room temperature and 9400 Mc per second. When the sample is stored in flowing nitrogen after irradiation, the composite spectrum decays with two different rates; similarly, for storage in vacuum. A dominant six-line component with peak separations of about 32 gauss, line widths of about 15 gauss, and intensity ratios of 1:4.6:10:9.9:4.5:1, decays to zero in about six days. The remaining component, which may itself be a mixture, appears to be chiefly a five-line spectrum (1:3.7:6.0:3.7:1) with roughly 20 gauss separations, obscured by additional structure; it decays slowly over many months with unchanging shape. Faster decay of the six-line component (attributed to $-CH_2CHCH_2-$ radicals) suggests these

radicals may be created as pairs (possibly by C-H scission plus hydrogen abstraction) and are the ones which lead to delayed crosslinking,[1] whereas the slowly-decaying radicals are either widely spaced or more restrained.

[1] Lawton, Powell, and Balwit, J. Poly. Sci. **32**, 288 (1958).

PA9. Paramagnetic Resonance Spectrum of Cobalt Doped Al_2O_3 at 1.6°K.* J. E. GEUSIC, *Bell Telephone Laboratories.*—The resonance spectrum of an Al_2O_3 crystal containing a small amount of Co has been studied at 1.6°K and 9.100 kMc/sec. These measurements establish that at this frequency the observed spectrum can be described by the following effective spin Hamiltonian:

$$\mathcal{H}=\beta[g_{11}'H_zS_z'+g_1'(H_xS_x'+H_yS_y')]+AI_zS_z'+B(I_xS_x'+I_yS_y'),$$

with $S'=\frac{1}{2}$, $I=\frac{3}{2}$, $g_{11}'=2.316\pm0.005$, $g_1'=4.98\pm0.01$, $(A/g_{11}'\beta)=31.0\pm0.5$ gauss, $(B/g_1'\beta)=42.0\pm0.5$ gauss, and where the z direction has been chosen to coincide with the c axis of the crystal.

* This work is partially supported by the Signal Corps.

PA10. Electron Spin Resonance of V^{++} and V^{+++} in Corundum.* JOHN LAMBE, R. AGER, AND CHIHIRO KIKUCHI, *Willow Run Laboratories.*—The paramagnetic resonance absorption signals at X-band frequency of di- and tri-valent vanadium in corundum single crystal, grown by Linde from 0.1% V_2O_3 powder mixture have been detected. In the magnetic resonance spectrometer, a lavite cavity was used. After x- and Co-60 gamma-irradiation, a spectrum detectable at room temperature can be developed, consistent with the assignment $S=\frac{3}{2}$ and $I=\frac{7}{2}$, suggesting V^{++}. The tentative values of the parameters in the spin-Hamiltonian are $A\sim B=88$ gauss; $D\sim9.4$ kMc/sec, and $g(V^{++})\sim g(Cr^{+++})$. The V^{+++} signal is detected at 4.2°K.[1] The hfs is strongly anisotropic, varying from 110 gauss at 0° to more than 350 gauss near 90°.

* Supported by Project MICHIGAN and Office of Scientific Research.
[1] Zverev and Prokhorov, JETP Soviet Physics **7**, 707L (1958).

PA11. Electron Spin-Lattice Relaxation at Low-Magnetic Fields in Phosphorus Doped Silicon.* E. STUPP AND A. HONIG. *Syracuse University.*—An investigation of the spin-lattice relaxation time τ_s of electrons associated with phosphorus donors in silicon has been carried out at low-magnetic fields with samples ranging in phosphorus concentration from 10^{14}P/cm³ to 10^{18}P/cm³. The magnetic field was varied between 0 and 3000 gauss, and the temperature was varied between 1.25°K and 3.0°K. The techniques used are similar to those reported in a previous investigation[1] of the high-magnetic field region (3000 to 11 000 gauss). A concentration dependent mechanism was found to be superimposed upon the concentration independent mechanisms throughout the entire concentration range investigated. This concentration dependent mechanism is dominant at 1.25°K and magnetic fields less than about 1500 gauss, but is nevertheless markedly manifest at 3000 gauss down to concentrations[2] of 10^{15}P/cm³. Below 10^{15}P/cm³, the H^4 mechanism[1] dominates at 3000 gauss. As an example of the duration of the relaxation times encountered in the dilute 10^{14}P/cm³ sample, at 1.25°K and 200 gauss τ_s exceeds 10^5 sec. The detailed magnetic field dependence, temperature dependence, and possible origin of the concentration dependent relaxation mechanism will be discussed.

* Work supported in part by the U. S. Air Force Office of Scientific Research.
[1] A. Honig and E. Stupp, Phys. Rev. Letters **1**, 275 (1958).
[2] G. Feher and E. A. Gere have reported concentration *independence* of the relaxation times for phosphorus concentrations below 10^{16} P/cm³, Bull. Am. Phys. Soc. Ser. II **3**, 415 (1958).

PA12. Certain Sum Rules Applicable to Paramagnetic Ions of Spin 3/2.* CHIHIRO KIKUCHI, *Willow Run Laboratories.*—In the design of masers, it is often necessary to carry out extensive numerical calculations because the crystalline field and Zeeman terms are comparable. The purpose of the present paper is to indicate that certain sum rules can be used to cross check the numerical work.[1] For example, if the crystalline field has axial symmetry, the sums of the relative intensities of the six possible transitions are given by $\Sigma I_{M'M}{}^{(x)}=12\cos^2\theta+5x^2$, $\Sigma I_{M'M}{}^{(y)}=12+5x^2$, $\Sigma I_{M'M}{}^{(z)}=12\sin^2\theta$, when the rf field is along the x, y, and z axis, respectively. Here the z axis is taken along the c axis, the dc magnetic field H in the xz plane at angle θ from z, and $x=g\beta H/|D|$. It is interesting to note that the intensities of complementary transitions are equal for any crystal orientation, if the rf field is along the dc magnetic field.

* Supported by the Air Force Office of Scientific Research.
[1] See also Geusic and Brown, Phys. Rev. **112**, 64 (1958). This paper gives other references.

PA13. Electron-Spin Paramagnetic Resonance of X-Ray LiF.* Y. W. KIM, R. KAPLAN, AND P. J. BRAY, *Brown University.*—Hyperfine splittings of the electron-spin resonances in x-rayed and neutron-irradiated LiF crystals have been investigated by Lord[1-3] and interpreted in terms of the F-center model of Seitz. The large second moment of the resonance envelope was explained in terms of M-center contributions. Recent investigations[4] of neutron-irradiated LiF in this laboratory have shown the presence of 29 or more components which are most clearly resolved with the magnetic field along [111] type crystal axes. Examinations of x-rayed LiF again yield more than 91 hyperfine lines. The shape and second moment of the envelope, and the hyperfine spacings and angular dependence of the spectrum, are the same as those found[4] in neutron-irradiated LiF. Optical examinations of both the x-rayed and neutron-irradiated crystals reveal only F and M-band responses. It appears that the present color-center models are not adequate in explaining these results.

* Work supported by the U. S. Atomic Energy Commission.
[1] N. W. Lord, Phys. Rev. **105**, 750 (1957).
[2] N. W. Lord *et. al.*, Bull. Am. Phys. Soc. Ser. II **1**, 12 (1956).
[3] N. W. Lord, Phys. Rev. **106**, 1100 (1957).
[4] Kim, Kaplan, and Bray, Bull. Am. Phys. Soc. Ser. II **3**, 178 (1958).

PA14. The "10/3 Effect" in Exchange-Narrowed Paramagnetic Resonances. R. N. ROGERS, M. E. ANDERSON, AND G. E. PAKE, *Stanford University.*—By observing the electron paramagnetic resonance of concentrated liquid solutions in chloroform of diphenyl picryl hydrazyl at frequencies of 30 Mc/sec, 6000 Mc/sec, and 9000 Mc/sec, we have looked for the "10/3 effect" proposed by Anderson and Weiss[1] and examined in theoretical detail by Kubo and Tomita.[2] The theory predicts, for Larmor frequencies well below the exchange interaction frequency, that the width of an exchange-narrowed resonance should be 10/3 as great as that for Larmor frequencies well above. We have observed a definite narrowing on proceeding to higher magnetic fields and frequencies, although there is not precise agreement with the theoretical expression of Kubo and Tomita, which involves some simplifying assumptions. Existence of the effect helps to corroborate the general theory, and it thus provides means for determining the exchange interaction, at least for samples in which g-anisotropy effects do not mask line narrowing in higher fields. In a 0.4-M solution we estimate $J/h\sim6\times10^9$ sec^{-1}.

[1] P. W. Anderson and P. R. Weiss, Revs. Modern Phys. **25**, 269 (1953).
[2] R. Kubo and K. Tomita, J. Phys. Soc. Japan **9**, 888 (1954).

PA15. Paramagnetic Resonance of Fe^{3+} Impurity in Octahedral and Tetrahedral Sites in Yttrium Gallium Garnet. S. GESCHWIND AND D. F. LINN, *Bell Telephone Laboratories.*—

The paramagnetic resonance spectrum of Fe^{3+} impurity in single crystals of yttrium gallium garnet[1] ($3Y_2O_3 \cdot 5Ga_2O_3$) has been studied at 24 000 Mc. The spectra associated with Fe^{3+} substituting for Ga^{3+} in both octahedral and tetrahedral sites have been observed and the signs as well as the magnitudes of the crystal field splitting parameters D, a, and F have been determined. The signs of these parameters were determined by comparing the intensity of the lines at room temperature 4.2°K and 1.5°K. The results will be compared with the theoretical predictions of Watanabe[2] and Lacroix.[3] The relation of these crystal field parameters to the anisotropy of ferrimagnets will be discussed with emphasis upon the anisotropy of yttrium iron garnet. It will be shown that the higher order axial term F is significant and must be taken into account in calculating the anisotropy of yttrium iron garnet.

[1] Grown by J. P. Remeika and J. W. Nielsen.
[2] H. Watanabe, Progr. Theoret. Phys. 18, 405 (1957).
[3] R. Lacroix, Helv. Phys. Acta 30, 478 (1957).

FRIDAY AFTERNOON AT 1:45

Willard, South Ballroom

(W. F. MEGGERS presiding)

Invited Paper

Q1. Ruling of Large Diffraction Gratings with Interferometric Control. G. R. HARRISON, *M.I.T.* (30 min.)

Line Spectra and X-Rays

Q2. Isotope Shifts in the RuI Spectrum.* R. H. HUGHES, *University of Arkansas.*—The hollow cathode spectra from isotopically enriched samples of ruthenium ($Z=44$) have been studied with the use of a Fabry-Perot interferometer. The following shifts in mK were measured for the λ4449-A line. The minus sign indicates a shift in the field effect direction.

98−96	100−98	102−100	104−102	99−98	101−100	104−96
∼−36.2	∼−15.2	−22.7	−25.1	∼+1.6	−4.3	−99.5

The uncertainty in the shifts relative to Ru-98 is brought about only by the isotopic impurity of the 98 sample. The estimated limit error on the other measurements is about ±1.6 mK. Although the minimum in the shifts between neutron numbers 56-54 might possibly be exaggerated a small amount (say 4 mK), there is little doubt that it exists. A similar minimum has been found in molydenum at these neutron numbers. The comparison of the 99-98 shift with a strong even-odd staggering effect found in molydenum (unpublished data by author) which produces a change in the sign of the shifts between neutron numbers 55-54 might support a contention that the Ru-98 position has not been chosen to exaggerate the 100-98 minimum. The presence of this minimum was predicted from nuclear deformation data as measured by Coulomb excitation experiments.

* Supported by the U. S. Air Force Office of Scientific Research.

Q3. Classification of the Pu II Spectrum. JOHN H. WISE, *Washington and Lee University and Oak Ridge National Laboratory.*—Extension of the work of McNally and Griffin[1] on the classification of the Pu II spectrum has proceeded by the measurement of 260 additional Zeeman patterns from the spectrograms obtained by Griffin at Oak Ridge National Laboratory and the calculation of least squares Landé g factors.[2] Using the McNally-Griffin levels as an extablished scheme, an intensive search of the Zeeman data (including McNally and Griffin's unclassified data) for new lower levels was undertaken. Significant progress has been made in the finding of a set of levels ascribed to the electron configuration $f^6(^7F)d$. The lower levels in McNally and Griffin's scheme arise from the $f^6(^7F)s$ configuration, which gives ^8F and ^6F terms; however, not all of the terms in this configuration have been observed. An $f^6(^7F)d$ configuration should generate terms which are octet and sextet P, D, F, G, and H. A tentative assignment of the new lower levels will be presented.

[1] J. R. McNally, Jr. and P. M. Griffin, J. Opt. Soc. Am. 49, 162 (1959).
[2] K. L. Vander Sluis, J. Opt. Soc. Am. 46, 605 (1956).

Q4. Measured Transition Probabilities for Lines of AI and AII. H. N. OLSEN, *Linde Company.*—Transition probabilities of selected argon emission lines have been obtained using the high current argon thermal plasma[1] as a source of known temperature in the range of 10 000 to 25 000°K. Radial distributions of absolute intensities, corrected for source inhomogeneities, have been measured using the positive crater of the low current pure carbon arc as a radiation standard. Measured intensities and temperatures have been combined with particle densities calculated by means of the Saha equation to give experimental values for the spontaneous transition probabilities. The estimated accuracy of measured probabilities is ±10%.

[1] H. N. Olsen, "Tenth annual gaseous electronics conference," Paper A-2 (1957).

Q5. Lower Bounds to Helium Atom Energy Levels. N. W. BAZLEY, *National Bureau of Standards* (introduced by J. P. Vinti).—We give the following rigorous bounds to the 1^1S and 2^1S energy levels of helium:

$$-2.9038777 \text{ a.u.} \leq E(1^1S) \leq -2.9037225 \text{ a.u.}$$
$$-2.165_5 \text{ a.u.} \leq E(2^1S) \leq -2.1458 \text{ a.u.}$$

The upper bounds are due to Kinoshita and to Collidge and James. Up to now attempts have been made to find lower bounds to $E(1^1S)$ by using the experimental value for $E(2^1S)$ in the application of Temple's formula. Our procedure is based on an essential modification of a method which goes back to A. Weinstein and was extended by Aronszajn. By neglecting the interaction between the electrons we obtain an explicitly solvable problem which gives rough lower bounds and which is called the *base problem.* We link this problem with the given one by a chain of *intermediate problems* which improve the lower bounds.

Q6. Excitation of 2S Atoms in Electron-Hydrogen Atom Collisions.* RONALD F. STEBBINGS, R. T. BRACKMANN, WADE L. FITE, AND DAVID G. HUMMER, *General Atomic.*—Measure-

ments of the absolute cross section for direct excitation of the hydrogen atom to the metastable $2S$ state by electron impact have been made for electron energies up to 30 ev. The metastable atoms were produced by the interaction of crossed electron and modulated ground-state atom beams. The current of $2S$ atoms produced was then quenched in an electrostatic field and the resulting Lyman-alpha radiation detected with an iodine-vapor-filled ultraviolet photon counter, using ac counting techniques. To assign absolute values to the relative measurements obtained in this way, the ratio of the $2S$ to the $2P$ excitation cross sections was determined. From a knowledge of the absolute cross section for excitation of Lyman-alpha radiation obtained previously, the absolute $2S$ excitation cross section was evaluated. In a separate experiment, the angular distribution of the scattered $2S$ atoms was also investigated for electron energies up to 500 ev.

* Supported by the Advanced Research Projects Agency through the Office of Naval Research.

Q7. Lifetime of the $2S$ State of Atomic Hydrogen.* WADE L. FITE, R. T. BRACKMANN, DAVID G. HUMMER, AND RONALD F. STEBBINGS, *General Atomic.*—A sensitive test for any mixing of the $2S_{\frac{1}{2}}$ and $2P_{\frac{1}{2}}$ states of atomic hydrogen is the measurement of the rate for single-quantum decay of the $2S$ atom to the ground state. A new upper limit of this decay rate has been determined. In the experiment a section along a beam of $2S$ atoms, produced by electron excitation of a ground-state atom beam, was viewed by an iodine-vapor-filled uv photon counter, which responds to the Lyman-alpha radiation of the single-quantum decay process. From the counts observed when an electrostatic quenching field was superimposed on the counter's field of view, the necessary experimental parameter (product of $2S$ atom current and counter efficiency) was determined. With the field removed, a portion of the remaining counts could be ascribed to quenching on collision of the $2S$ atoms with residual gases in the vacuum chamber, the quenching cross sections for which were measured. The decay rate not ascribable to known quenching effects was 420 sec^{-1}. Since unknown quenching effects may have been operative, this figure must be considered as only an upper limit. Using the formulas of Salpeter, an upper limit for an electric dipole moment of the electron is 0.0045 $e\hbar/mc$.

* Supported by the Advanced Research Projects Agency through the Office of Naval Research.

Q8. Narrow Linewidths for Decaying States by the Method of Separated Oscillating Fields. VERNON W. HUGHES, *Columbia University.*—The transition probability by the method of separated oscillating fields[1] has been computed for the case in which one of the two states has an optical decay rate γ. The line pattern has a narrow central peak with frequency width of the order of $1/T$ in which T is the transit time of the atom between the two oscillating field regions. The amplitude of this peak is lower than the amplitude of the principal broad peak by the order of $\exp(-\gamma/2T)$. The narrow central peak, whose frequency width may be less than the width corresponding to the decay rate γ, arises, of course, from the interference effect characteristic of the method of separated oscillating fields. The availability of a copious source of fast hydrogen atoms in the metastable $2^2S_{\frac{1}{2}}$ state[2] may make it possible to utilize the narrow linewidth obtainable by the method of separated oscillating fields for more precise measurements of the fine structure of hydrogen.[3]

[1] N. F. Ramsey, Phys. Rev. **78**, 695 (1950).
[2] Private communication from L. Madansky.
[3] I believe that the idea of obtaining a narrow line width for decaying states by the separated oscillating fields method was first suggested by R. H. Dicke.

Q9. Absorption of 250-Mev Photons in Low Z Materials. W. B. JONES, *General Electric Company.*—Transmission measurements have been made on some low Z materials in the energy range 150–250 Mev. The 300-Mev nonferromagnetic synchrotron[1] was used as the photon source and a magnetic pair spectrometer as the detector. The transmission of liquid hydrogen yields a tentative value of 18.5 mb for the total cross section. This cross section is constant in the 150–250-Mev energy range. This result is in close agreement with the theoretical prediction of Wheeler and Lamb[2] if it is assumed that the Compton cross section is correctly given by the Klein-Nishina formula. The transmission of Be and C were also measured and the results will be presented.

[1] W. B. Jones *et al.*, Rev. Sci. Instr. **26**, 809 (1955).
[2] J. A. Wheeler and W. E. Lamb, Phys. Rev. **55**, 858 (1939); **101**, 1836 (1956).

Q10. Soft X-Ray Bremsstrahlung from a Copper Target.* T. J. PETERSON, JR., AND D. H. TOMBOULIAN, *Cornell University.*—The intensity distribution in the continuous soft x-ray spectrum emitted by a copper target has been investigated by means of a grazing incidence vacuum spectrograph. The radiation was generated in a specially designed tube which was operated at 3 kv with a current of 200 ma. The emitted photons were collected at an angle of 110° from the forward direction of the electron beam. The relative intensities were determined photometrically over the spectral region extending from the $M_{2,3}$ edge at 164 A down to the instrumental cutoff located approximately at 60 A. The spectral response of the particular grating had been examined previously,[1] hence, in conjunction with an empirical relation proposed by Stephenson and Mason[2] it was possible to predict the over-all shape of the spectrum. The result of this calculation will be compared with the observations carried out over the long wavelength distribution of the very low voltage Cu spectrum. Comments will be made upon the effect of self-absorption in the target.

* Supported in part by the U. S. Army Office of Ordnance Research.
[1] Sprague, Tomb ulian, and Bedo, J. Opt. Soc. Am. **45**, 756 (1955).
[2] S. T. Stephenson and F. D. Mason, Phys. Rev. **75**, 1711 (1949).

Q11. Soft X-Ray Emission Spectra of some Binary Transition Group Alloys. K. DAS GUPTA,* *The Ohio State University* (introduced by E. L. Jossem).—The K and L spectra of Al, the K spectrum of Si and the L spectra of Fe, Co, Ni, and Cu have been investigated in Fe-Al, Fe-Si, Fe-Cu, Co-Cu, and Ni-Cr alloys of different percentage compositions with the help of bent crystal and ruled grating spectrographs. The L spectra of Fe in FeS (below and above the Curie point) and in magnetic iron oxide have also been studied. The essential findings are (1) a prominent structure immediately on the short wavelength side of $L\alpha$ of Fe and Co in alloys, (2) the position of the newly observed $3d$ band structure is independent of the alloying element and appears at about 3-ev gap from the main $L\alpha$ peak, (3) the intensity of the new $3d$ band structure increasess as the percentage of the nonferrous constituent increases, (4) the $3d$ band of magnetic iron sulphide shows similar structure on the short wavelength side of $L\alpha$, only when above the Curie point. (5) $K\alpha_{1,2}$ lines of Al and Si in alloys shift towards the shorter wavelength side establishing that Al and Si behave as donors of electrons in ferrous alloys.

* Permanent address: University of Calcutta.

FRIDAY AFTERNOON AT 2:00

National Bureau of Standards, East Building

(HARVEY BROOKS presiding)

Solid-State Physics, Mostly Metals

QA1. Interaction of a Dislocation with a Simple Tilt Dislocation Boundary. JAMES C. M. LI, *United States Steel Corporation.*—An elastic theory analysis gives the following results: (1) a pinned dislocation wall attracts or repels an approaching dislocation less than a single dislocation situated at the distance of the wall; (2) a dislocation wall with a free dislocation attracts an approaching dislocation on the same slip plane as that of the free dislocation to form a stable structure with two dislocations placed symmetrically on two sides of the wall; (3) this stable structure becomes unstable when another dislocation on the same slip plane as that of the two dislocations approaches the wall closer than 8 dislocation spacings in the wall; (4) a pinned dislocation wall attracts the first approaching dislocation on a slip plane between two dislocations in the wall but repels the second one; (5) two consecutive free dislocations in a wall oscillate back and forth when an approaching dislocation glides through the wall between them; and (6) a dislocation wall with three consecutive free dislocations attracts an approaching dislocation on the same slip plane as that of the middle one to form the same stable structure mentioned above. Thus the theory indicates that a symmetric tilt boundary is not a very effective barrier to the penetration of dislocations.

QA2. Optical Transition Radiation from Protons. P. GOLDSMITH AND J. V. JELLEY.* *Atomic Energy Research Establishment, Harwell* (introduced by N. Bloembergen).—It has been predicted[1,2] that weak radiation is emitted when a charged particle enters a metal surface, due to the annihilation of the dipole formed by the charge and its image. Experiments were conducted to observe this effect, by bombarding clean Al, Ag, and Au targets with 1–5 Mev protons, and receiving the light with a cooled photomultiplier. The results, which confirm the theory, are: (1) the light was found to be polarized, in the expected sense; (2) the absolute yield of the polarized light agreed reasonably with that predicted, namely, 3.6×10^{-10} photons·proton^{-1}·A^{-1} sterad^{-1} for 1-Mev protons, at $\bar{\lambda}=4000$ A and viewing angle 90°; and (3) the excitation function increased linearly with proton energy. There was an unpolarized component attributed to surface fluorescence and ionization of resiudal gas, also backgrounds due to dark current and nuclear radiations. Five other effects, which might contribute to polarized light, are all shown to be negligible compared with the transition radiation.

* At present at Harvard College Observatory, Cambridge, Massachusetts.
[1] I. M. Frank, and V. L. Ginsburg, J. Phys. (U.S.S.R.) 9, 353 (1945).
[2] G. M. Garibian, Soviet Phys. JETP 6, 1079 (1958).

QA3. The Work Function of the (100) Plane of Iron Produced by Cleavage in High Vacuum. RALPH E. SIMON,* *Cornell University.*—The work function of the cleavage plane of a single crystal of iron, prepared by cleavage in high vacuum ($p<10^{-9}$ mm Hg) at 77°K, was measured by the Kelvin contact potential difference method using polycrystalline tungsten ribbons for reference surfaces. The tungsten ribbons were flashed at 2400°K less than 15 seconds before the cleavage of the iron. Since measurements were made within two minutes after the iron was cleaved, and the cpd was changing by only 0.001 volt/minute, the results could be extrapolated to the time of cleavage to get the cpd between clean iron and clean tungsten. The tungsten was aged by heating at 2700°K for one hour. The work function of such ribbons has been measured by Apker, Taft, and Dickey.[1] Using their value for the work function of tungsten, the work function of iron was found to be 4.17 ± 0.03 volts. Measurements in which the same tungsten ribbon was used against several cleavage faces gave the same values of cpd to ±0.01 volt. Consideration of the mechanisms by which the cleaved surfaces might be contaminated indicates that these surfaces are clean.

* Now at RCA Laboratories, Princeton, New Jersey.
[1] Apker, Taft, and Dickey, Phys. Rev. 73, 46 (1948).

QA4. Activation Energy for Grain Growth in Nickel from Double Bragg Scattering.* R. L. WILD AND W. T. OGIER, *University of California, Riverside.*—The double Bragg process produces about 99% of small angle x-ray scattering observed in plastically deformed metals.[1] Calculation of the expected scattering[2] predicts the intensity proportional to the sum of fourth powers of the radii of recrystallized grains. This was used to measure the rate of grain growth in nickel reduced in thickness by rolling. The samples were vacuum annealed, stretched in the beam, and the rise in scattering observed. Plots of the fourth root of the maximum x-ray intensity *vs* time for several temperatures were straight lines starting from a common origin. These results indicate that a block theory of recrystallization is correct for nickel at these deformations. Activation energy for grain growth was approximately constant for 27%, 37%, 53%, and 67% reductions in thickness with an average value of 70 kcal/mole. The starting block was about 10 microns for 53% reduction as judged from final grain size and slope of curve. Initial block size depends on degree of deformation.

* Supported by the Office of Ordnance Research, U. S. Army.
[1] International Symposium on Small Angle X-ray Scattering, Kansas City, Missouri, September 23–25, 1958, J. Appl. Phys. (to be published).
[2] Ogier, Wild, and Nickel, J. Appl. Phys. 30, 412 (1959).

QA5. Diffusion Coefficient of Cobalt in Copper from Precipitation Measurements. J. W. CAHN, *General Electric Research Laboratory.*—When cobalt precipitates from dilute (0.4–2.0% cobalt) copper solid solution in the range of 400°–700°C more than 10^{16} and up to 10^{19} cm^{-3} precipitate particles form. Precipitation is thus on a much finer scale than the defect network structure. The number of particles and their size have been measured magnetically as a function of time and temperature. From the growth rate of these particles an apparent diffusion coefficient may be computed.

Mackliet[1] has measured the diffusion coefficient of cobalt in pure copper single crystals in the temperature range 701.4–1077.5°C by the standard tracer—sectioning techniques. He finds that the plot of log$D$ against $1/T$ curves upward below about 820°C. This phenomenon might be due to substructure even though the plot of activity *vs* square-of-penetration was linear.

A comparison of the diffusion coefficient computed from the growth rate of the precipitate supports this explanation of the upward curvature. Within experimental error, the diffusion coefficient obtained from precipitation for the temperature range 400°C–600°C for 0.4% and 0.8%, cobalt agrees with the equation given by Mackliet for his points above 820°C, with $D_0=1.93$ cm^2/sec and $Q=54.1$ kcal/mole. The diffusion coefficients for the 1.3 and 2.0%

cobalt samples in the range 700–470°C lie slightly below this line.

[1] C. A. Mackliet, Phys. Rev. **109**, 196 (1958).

QA6. The Structure of Vacuum-Deposited Films as Determined from the Total Reflection of X-Rays.* N. WAINFAN, R. SVIEDRYS, M. HANE, AND L. G. PARRATT, *Cornell University.*—A vacuum x-ray reflectometer has been constructed to allow measurement of the coefficient of reflection of optically flat surfaces at small glancing angles while the mirror is contained in a temperature-controlled vacuum chamber. This instrument has been applied to the study of metal films vacuum-deposited onto optically flat glass and Pyrex substrates. The x-ray wavelength used in this work is 1.54 A. A measurement of the x-ray reflection coefficient as a function of glancing angle yields information about the density, the density distribution and thickness of the metal film.[1] The new instrument extends previous investigations[2,3] to the study of the oxidation-reduction and annealing processes. Data will be presented illustrating the effects of the oxidation, reduction, and anneal on copper films in the thickness range between 400 and 1200 A. X-ray reflection curves will be interpreted in terms of possible film structures.

* Supported in part by the U. S. Air Force through the Office of Scientific Research in the Air Force Research and Development Command.

[1] L. G. Parratt, Phys. Rev. **95**, 359 (1954).

[2] R. C. Duncan, Jr. and L. G. Parratt, Bull. Am. Phys. Soc. Ser. II, **2**, 215 (1957). Nancy J. Scott and L. G. Parratt, Bull. Am. Phys. Soc. Ser. II, **2**, 215 (1957).

[3] Wainfan, Scott, and Parratt, "Density measurements of some thin copper films" (to be published).

QA7. (Abstract withdrawn.)

QA8. Strain Resistance Effects in Metallic Whiskers.* HERMAN H. HOBBS AND N. CABRERA, *University of Virginia.*—The effect of large elastic strains on the resistivity of whiskers of Cu, Ag, Fe, and Zn has been studied. The maximum strains obtained were of the order of 0.02, extending the range of previous observations considerably. The effects observed are essentially linear although small second-order effects are observable. The strain-resistivity tensor, $(\Delta\rho/\rho)_{ij} = K_{ijkl}\epsilon_{kl}$, for Cu whiskers has been determined. The theoretical interpretation of these measurements will be discussed.

* This work supported by the Office of Naval Research.

QA9. Internal Whisker-Like Precipitates in Silver Chloride Crystals.* CHARLES CHILDS AND LAWRENCE SLIFKIN, *University of North Carolina.*—Whisker-like formations within single crystals of AgCl have been observed after the following treatment. Internal specks of print-out silver were produced in Harshaw crystals by means of the Haynes-Shockley sweeping technique. The crystals were then annealed for 40 hours in air at 425°C. The cloud of silver disappeared, leaving in its place fine, straight precipitates. The degree of formation of these filaments varies among specimens. The "whiskers" have lengths of the order of a few tenths of a mm (up to 0.6 mm) and are about 2 microns in diameter. They are perfectly straight, display no observable uneveness along their sides, and are oriented along the 6 crystallographic (110) directions. Upon dissolving away the AgCl with dilute KCN, the "whiskers" are found to crumble. Thus, although they have all the morphological characteristics of the usual, externally grown whiskers, they lack the expected mechanical strength and cohesion.

* Supported by the Office of Ordnance Research, U. S. Army.

QA10. A Preliminary Study of Some Nonmetallic Whiskers. P. J. BRYANT, *Midwest Research Institute.*—Whiskers of several alkali halide compounds, including NaCl and KCl, were grown from solution by slow diffusion through a semi-permeable membrane. Other nonmetallic whiskers were grown by deposition from solutions and vapors. Structural features and growth mechanisms were studied by means of optical and electron microscopy. The alkali halide whiskers were readily adaptable to dark field and oil immersion techniques. They were also readily decomposed, at controllable rates, by the beam of the electron microscope. Structural details of the whisker surfaces were enhanced by immersion in a gold solution. Several interesting growth features were observed, including axial pores, multiple whiskers, and combinations of whiskers and platelets. The relation of these growth features to the dislocation content will be discussed. Several stages of growth, as described by Amelinckx,[1] were observed.

[1] S. Amelinckx, Physica **24**, S, 390 (1958).

QA11. Charging of Polymer Samples by Repetitive Metal Contact. EDWARD L. KERN AND SELBY M. SKINNER, *Case Institute of Technology.**—The charging of polystyrene and poly(methylmethacrylate) on contact with metal surfaces has been studied by repetitive intermittent pressure contacts between two planar surfaces. The intermittent method permits suitable correction for circuit parameters and provides an expanded scale of data points for precision. Polymer samples are made with high purity methods, and aged and tested in a nitrogen atmosphere. Metal surfaces are freshly ground in toluene suspension to give a planar ground surface essentially free from oxide or other impurity layers. The charge increase is a smoothly varying curve proceeding to a maximum voltage which, for any one metal, is a function of the composition of the polymer, and of its insulation during test. Poly(methylmethacrylate) charges positively with aluminum and all other metals tried, the timewise course of the potential being representable as $V = V_f[1 - \exp(-nb)]$, where V_f is the final potential, n is the number of contacts, and b a charging parameter. The charging parameter is dependent upon the initial charge on the polymer surface, and this is correlated with the effects of the different methods of monomer purification. Polystyrene charges negatively, also as a smoothly varying function of the same type.

* With the support of the Office of Ordnance Research, and the Manufacturing Chemists Association.

QA12. Role of Adhesion in Metallic Wear and Friction. DEREK WALTON, *Physics Section, Convair-San Diego* (introduced by D. B. Medved).—Since even the most carefully prepared surfaces are covered with asperities which are large with respect to atomic dimensions contact between solid surfaces is established at only a few points. It is widely accepted that adhesion occurring at the junctions of asperities

is responsible for a frictional force and the production of wear particles. The production of wear particles requires that the strength of the junctions exceed that of the solids themselves. Although adhesive forces can be measured in a high vacuum these forces in general, cannot be observed in air. It is shown that in those cases where an adhesive force is measured in a vacuum, but no adhesive force can be measured in air, the junctions in air cannot be stronger than the bulk material. Further difficulties with the present theory of wear are discussed; the presence of loose wear particles and the production of fragments of the harder surface during sliding between dissimilar materials. An alternate theory of wear is discussed on the shearing of interlocked asperities and it is observed that a mechanism of this sort will also lead to a frictional force.

QA13. Effect of a High Temperature Gradient on Diffusion in Cu-Ni Couples.* C. J. MEECHAN AND W. G. BRAMMER, *Atomics International*.—Theory[1-3] predicts that net mass transport of matter should occur when metals in which the vacancy mechanism of diffusion is operative are subjected to high temperature gradients. The direction of the net mass flow in the temperature gradient depends on the relative magnitudes of the vacancy formation energy, E_f, and migration energy, E_m. This effect has not yet been observed in pure metals. In the present work, Cu-Ni diffusion couples, in which a net mass transfer occurs under isothermal conditions due to the chemical concentration gradient, have been subjected to temperature gradients of about 3000°C/cm. Significantly different results in the rate of mass transfer are observed in each of the following cases: (1) a specimen heated isothermally, (2) one heated in a temperature gradient with the Ni at the high temperature, and (3) one heated in a temperature gradient with the Cu at the high temperature.

* Work supported by the U. S. Atomic Energy Commission.
[1] W. Shockley, Phys. Rev. **91**, 1563 (1953); **93**, 346 (1954).
[2] A. D. LeClaire, Phys. Rev. **93**, 344 (1954).
[3] J. A. Brinkman, Phys. Rev. **93**, 345 (1954).

FRIDAY AFTERNOON AT 2:00

Room B in Departmental Auditorium

(GREGORY BREIT presiding)

Theory, IV: High-Energy Scattering

R1. Chew-Low Formalism for Two Nucleon-Meson Systems. WILLIAM FRANK, *Brookhaven National Laboratory*.*—A formalism analogous to the Chew-Low formalism is constructed for the system of two fixed nucleons interacting with symmetric pseudoscalar mesons. The resulting physical dinucleon states consist of two fixed nucleons and their meson cloud which may include scattered mesons asymptotically. The energies of the ground states apart from self-energies are just the static nuclear forces. An integral equation for them has been obtained and is being studied. Matrix elements of meson field operators between physical dinucleon states can be expressed in terms of matrix elements of spin-isospin operators and propagators as in the one nucleon Chew-Low theory. Symmetry arguments give the form of matrix elements of spin-isospin operators between physical dinucleon states to within certain unknown functions of the internucleon separation. Theoretically these functions can be expressed in terms of three unknown functions by means of a very complicated Low integral equation. For the purposes of application these functions are determined by assuming a simple model where spin transitions in one nucleon take place independently of the presence of the other nucleon. The formalism is applied to the photodisintegration of the deuteron. Results will be reported.

* Done in part at Massachusetts Institute of Technology.

R2. Momentum and Angle Distributions for Dalitz-Decaying Neutral Pions. J. G. DARDIS AND V. P. KENNEY, *University of Kentucky*.*—The Dalitz mode of decay of $\pi^0 \to e^+ + e^- + \gamma$ has been used to obtain identification of neutral pions produced in $\pi^- - p$ interactions at 1 Bev/c. Distributions of scattering angle, momentum, apparent "Q" values, and angular correlations have been calculated for all emitted particles, and the results compared with nucleon isobar theory[1] and specific pion-pion interaction models.[2]

* The cooperation of the UCRL hydrogen bubble chamber group is acknowledged with appreciation.
[1] S. J. Lindenbaum and R. M. Sternheimer, Phys. Rev. **106**, 1107 (1957); *ibid.* **109**, 1723 (1958).
[2] F. J. Dyson, Phys. Rev. **99**, 1037 (1955); G. Takeda, Phys. Rev. **100**, 440 (1955).

R3. Lowest Order Velocity Dependent Nuclear Force from Pion Field Theory.* M. SUGAWARA AND M. T. VAUGHN, *Purdue University*, AND SUSUMU OKUBO, *University of Rochester*.—Velocity dependent two-nucleon potential has been derived from relativistic *ps-ps* pion field theory up to the lowest order of both coupling constant and pion-nucleon mass ratio, using Tamm-Dancoff formalism. The result obtained is not the same, but of similar general feature, as the one obtained from *ps-pv* pion field theory using the same procedure.[1] The detail of the derived potential will be reported, with particular emphasis on comparison of this potential with the $L \cdot S$ potential thus far proposed.[2]

* Research supported in part by the U. S. Air Force Office of Scientific Research and the National Science Foundation.
[1] S. Okubo and R. E. Marshak, Ann. Phys. **4**, 166 (1958).
[2] P. S. Signel and R. E. Marshak, Phys. Rev. **106**, 832 (1957); **109**, 226 (1958); J. L. Gammel and R. Thaler, Phys. Rev. **107**, 291 (1957); *ibid.* **107**, 1337 (1957).

R4. Procedure for Calculating the Matrix Element of the Process ($N\bar{N}/2\pi$).* JOSE R. FULCO,† *University of California, Berkeley*.—The problems of nucleon-nucleon interaction and nucleon electromagnetic structure involve the matrix element for two pions producing a nucleon-antinucleon pair. By use of the Mandelstam representation[1] we are able to write dispersion relations for the partial-wave scattering amplitudes of this process. In the energy range of interest these dispersion relations can be transformed into integral equations whose kernels are simply related to pion-nucleon and pion-pion scattering amplitudes. A preliminary solution of the equations, based on experimental pion-nucleon phase shifts and theoretical pion-pion phase shifts, will be presented.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† A visitor from the Argentine Army.
[1] S. Mandelstam, Phys. Rev. **112**, 1344 (1958).

R5. Optical Model Potential for the K^--Nucleus Scattering.* FABIO FERRARI, *University of California, Berkeley*,† AND LUCIANO FONDA, *Indiana University*.‡—The nuclear interactions of K^- mesons in photographic emulsions are

analyzed in terms of the optical model of the nucleus. The elevant parameters are calculated from the K^--nucleon scattering data[1] on the assumption that these forces are not appreciably modified within nuclei.[2] Comparison with the experimental evidence yields the sign of the complex singlet and triplet K^--proton scattering amplitudes. Further analysis gives some information on the K^--neutron scattering length.

* This research was supported in part by the National Academy of Science and by the National Science Foundation.
† On leave of absence from Padua University.
‡ On leave of absence from Trieste University on a Fulbright traveling grant.
[1] Jackson, Ravenhall, and Wild, Nuovo cimento 9, 834 (1958).
[2] Frank, Gammel, and Watson, Phys. Rev. 101, 891 (1956).

R6. Phase Shifts for *P-P* Scattering at 150-Mev.* R. C. STABLER, *Cornell University.*—A phase-shift solution up to F waves of the type of Stapp's solution six[1] has been found for proton-proton scattering at 150 Mev which fits the recent differential cross section, polarization, and depolarization results obtained at Harvard.[2,3] Another set to fit Taylor's depolarization data[4] has also been obtained. The search was performed by expanding to second order $M=\Sigma[f_s(\theta)-f(\theta,\delta_{lj})]^2/[\Delta f_s(\theta)]^2$ about a trial solution, Phillips' solution 3*b*.[5]

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Stapp, Ypsilantis, and Metropolis, Phys. Rev. 105, 307 (1957).
[2] Palmieri, Cormack, Ramsey, and Wilson, Ann. Phys. 5 (1958).
[3] Hwang, Ophel, Ramsey, Thorndike, and Wilson, Bull. Am. Phys. Soc. Ser. II, 4, 61 (1958).
[4] A. E. Taylor, Proceedings of the Rochester Conference (1957) and Proceedings of the 1958 CERN Conference.
[5] R. J. N. Phillips, Nuovo cimento 5, 1335 (1957).

R7. Dispersion Relation for *s*-Wave Nucleon-Nucleon Scattering.* D. Y. WONG, *University of California, Berkeley,* AND N. P. NOYES, *University of California, Livermore.*—According to the Mandelstam's representation,[1] the scattering amplitude is an analytic function of both the energy and the momentum-transfer variables except for singularities on the real axes corresponding to thresholds for permissible intermediate states. It follows that each partial wave amplitude also has singularities only on the real axis of the energy variable, and hence satisfies a dispersion relation. If one neglects all but the one-meson branch point plus the branch point for the threshold of the physical region, then, together with the unitarity condition, the singlet s-wave phase shift can be solved in terms of the coupling constant and the subtraction constants. When one subtraction is made to fit the scattering length, an effective range of approximately one-half the experimental value is obtained. If one makes two subtractions to give the correct scattering length and the effective range, then the deviation of $k\cot\delta_0$ from the straight-line plot can be calculated in terms of the coupling constant.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] S. Mandelstam, Phys. Rev. 112, 1344 (1958).

R8. Nucleon-Nucleus Scattering at 150 Mev.* ALAN CROMER, *Cornell University.*—An analysis of the small-angle scattering and polarization of protons from He and C at 147 Mev and 135 Mev, respectively, has been made using a method similar to that employed at 310 Mev.[1,2] By subtracting out Coulomb effects the spin-independent and spin-dependent parts of the nuclear scattered amplitudes are determined directly from the experimental data. These amplitudes have been used to calculate the neutron-nucleus scattering and polarization and give results in good agreement with experiment. These amplitudes have also been derived from optical potentials deduced from the Signell-Marshak and the Gammel-Thaler nucleon-nucleon potentials in a manner previously described.[2,3] The results of this calculation are unsatisfactory: the imaginary part of the spin-independent amplitude comes out too large, whereas the real part comes out too small. The calculation has therefore been modified to take account of effects due to the exclusion principle. The results of this calculation will be presented.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] H. A. Bethe, Ann. Phys. 3, 190 (1958).
[2] A. Cromer, Phys. Rev. (to be published).
[3] A. Cromer, Bull. Am. Phys. Soc. Ser. II, 4, 49 (1959).

R9. Potential-Boundary Condition Description of Nucleon-Nucleon Scattering.* A. TUBIS,† *MIT.*—A fairly satisfactory description of nucleon-nucleon scattering from 0 to 350 Mev, as well as the deuteron data, has been obtained by means of a potential which is supplemented at small distances by boundary conditions of the Feshbach-Lomon type.[1] At large distances the potential approaches the second-order potential obtained from pseudo-scalar meson-nucleon coupling. The coupling constant is taken from the pion-nucleon scattering and photoproduction data. The potential is qualitatively similar to that of Gartenhaus[2] for distances greater than about $0.5f$. There is no spin orbit term in the potential. Two different potentials have been found, which correspond, respectively, to exact fits of the Stapp *et al.* 310-Mev phase-shift solutions 1 and 6.[3]

* Work supported in part by an Eastman Kodak Predoctoral Fellowship (1957–1958).
† Now at the Worcester Polytechnic Institute.
[1] H. Feshbach and E. Lomon, Phys. Rev. 102, 891 (1956).
[2] S. Gartenhaus, Phys. Rev. 100, 900 (1955).
[3] Stapp, Ypsilantis, and Metropolis, Phys. Rev. 105, 302 (1957).

R10. Generalized Diffraction Theory for Very-High-Energy Collisions.* K. R. GREIDER AND A. E. GLASSGOLD, *University of California, Berkeley.*—A quite general method has been developed for the analysis of the scattering of high-energy particles from spherically symmetric targets. In such processes the scattering amplitude, $f(\theta)$, can be written in a general way as a sum over all l of $(2ik)^{-1}[(2l+1)(\eta_l-1)P_l(\cos\theta)]$, where η_l is the amplitude of the lth partial outgoing wave. The well-known "black sphere" model[1] assumes $\eta_l=0$ for $l<L$, and $\eta_l=1$ everywhere else. In generalizing this model, we have assumed that at high energies η_l is an analytic function of l, and depends on four parameters: L, the number of partial waves strongly absorbed; 2Δ, the transition region, centered around L, over which the absorption of partial waves vanishes; β, the amount of absorption, or opacity, for $l=0$ waves; α, the phase of the scattered wave. Like the optical model, our diffraction model gives a general four-parameter scattering formalism in which the parameters may be deduced from experimental data. The significant advantage of this method, however, is that the sum over partial waves can be carried out explicitly and yields simple closed-form expressions for the total, reaction, and differential cross sections. Various applications of this method will be discussed as well as extensions to include spin orbit and Coulomb processes.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] H. A. Bethe and G. Placzek, Phys. Rev. 57, 1075(A) (1940); A. Akhieser and I. Pomeranchuk, J. Phys. 9, 471 (1945).

R11. Application of Dispersion Relations to the Photodisintegration of the Deuteron. BUNJI SAKITA, *University of Rochester* (introduced by C. Goebel).—Assuming the validity of the two-dimensional dispersion relations (Mandelstamm) for the photodisintegration of the deuteron, we can make a set of dispersion relations for the angular momentum amplitudes. The deuteron is described by a pseudovector field with Lorentz condition. There are three pole terms, coming from the one deuteron, one neutron, and one proton intermediate states. We need the neutron proton deuteron vertex part; we calculate this by Nishijima's composite particle theory. We assume no subtractions are needed. At first, considering the low-energy photodisintegration, we may neglect the contribution from intermediate states containing pions, and likewise the contri-

bution from the negative energy region to the dispersion integral. We take the phase of the transition amplitude to be the phase shift of the final neutron-proton scattering. Solving these integral equations, we can get the transition amplitude as an integral over these phase shifts. Picking up only the electric dipole and magnetic dipole terms, neglecting the D state part of the deuteron ground state, neglecting the ^3P phase shifts (for $E1$), and using the effective range approximation to the ^1S phase shift (for $M1$), we get the same result as the usual calculation. We can easily omit some of the above approximations.

R12. Theory of the Photodisintegration of the Deuteron.* L. D. PEARLSTEIN AND ABRAHAM KLEIN, *University of Pennsylvania.*—A covariant field theoretic technique[1] has been employed to derive a formally exact expression for the amplitude for photodisintegration of the deuteron. Assuming that the meson-meson interaction is unimportant and that nucleons interact via p-wave mesons only, we can, by invoking the adiabatic approximation and by limiting ourselves to single meson exchanges, reduce this expression to one in which the corrections to the conventional matrix element depend only on the amplitude for photomeson production, the renormalized meson-nucleon coupling constant, and the appropriate two nucleon wave functions. The results of the numerical analysis, which are in rather good agreement with experiment for the energy range 0 to 400 Mev,[2] indicate that virtual mesons play an unimportant role at low energies as predicted by Siegert's theorem,[3] and that the total and folded differential cross sections, at the higher energies (150 to 400 Mev) can only be predicted if we include the D state of the deuteron and employ hard core wave functions in the initial and final state.

* Supported in part by the U. S. Atomic Energy Commission.
[1] A. Klein and C. Zemach, Phys. Rev. 108, 126 (1958).
[2] We have included the results of the calculation at the lower energies by J. J. de Swart and R. E. Marshak, Phys. Rev. 111, 272 (1958).
[3] A. J. F. Siegert, Phys. Rev. 49, 904 (1936).

FRIDAY EVENING AT 7:00

Willard, Grand Ballroom

(G. E. UHLENBECK presiding)

***Banquet of the American Physical Society* (*Cocktail Party Preceding*)**

After-dinner speaker: The Honorable Lewis L. Strauss.

SATURDAY MORNING AT 9:00

Willard, Grand Ballroom

(K. R. SYMON presiding)

Accelerators and Other Nuclear Apparatus

S1. Resonant Beam Knock-Out from an *A-G* Synchrotron.* L. JACKSON LASLETT AND C. L. HAMMER, *Iowa State College and Midwestern Universities Research Association.*—In continuation of work previously reported[1,2] for a normally constant-gradient synchrotron, the effect of field-index perturbations (n-bumps) in producing an instability potentially helpful for beam utilization is examined analytically for an alternating-gradient accelerator and illustrated by computational examples. The perturbations are chosen to open a stop-band (frequency ν_s) within which the solution to the (linear) equation for radial oscillations soon becomes dominated by an oscillation of exponentially-increasing amplitude. A field-index perturbation containing circular functions of argument $(\nu_s+r)\theta$ *and* $(\nu_s-r)\theta$ can open such a stop-band, and a circular function of argument $2\nu_s\theta$ can be particularly effective. The azimuthal dependence of the perturbation also influences the *form* of the unstable solution, a term of argument $(\nu_s\pm r)\theta$ serving to introduce a sinusoidal variation of argument $r\theta$ into the solution, and such terms with $r=\frac{1}{2}$ may be particularly useful. To achieve specific desirable features of the solution, careful attention to meeting the requisite tolerances for the perturbation may be necessary and should be estimable by the general methods of this investigation.

* Computational work performed with the MURA IBM 704 computer with the support of the U. S. Atomic Energy Commission.
[1] L. Jackson Laslett and Charles L. Hammer, Bull. Am. Phys. Soc. Ser. II, 3, 180 (1958).
[2] C. L. Hammer and L. J. Laslett, Second Internat. Conf. on Peaceful Uses of Atomic Energy (Geneva, Switzerland, 1958), Paper A/CONF. 15/P/726.

S2. Two-Way Storage Rings.* GEORGE PARZEN,† *Midwestern Universities Research Association.*—It is possible to visualize, at the present time, at least two different kinds of two-way storage rings. One kind is simply a modification of the two-way FFAG accelerator proposed by T. Ohkawa in which the particle moves alternately through positive and negative magnetic fields. A second kind is of the sort proposed by G. K. O'Neill in which the particle always moves through a magnetic field of the same sign. The properties of the Ohkawa type have been investigated. It has been found that the smallest circumference factor obtainable is roughly 4.5. This optimum circumference factor is achieved in the linear storage ring. Theoretical results for the equilibrium orbit and tune of the linear storage ring will be presented, and will be compared with the results of numerical calculations.

* Supported by the U. S. Atomic Energy Commission.
† On leave from the University of Notre Dame.

S3. Injection into Accelerators by a Programed Perturbation.* F. E. MILLS AND T. O. BINFORD, *Midwestern Universities Research Association.*—The introduction of a field perturbation into an accelerator generates a new equilibrium orbit about which particles oscillate. If particles are injected near this new orbit, and the perturbation turned off adiabatically, the particles will follow the equilibrium orbit as it returns to its unperturbed position. Particles injected during the turnoff of the perturbation will have betatron oscillation amplitudes which depend upon the position of the equilibrium

orbit when they are injected. During the time in which the betatron oscillation phase returns to its initial value, the equilibrium orbit must be moved by the width of the injected beam and the septum of the inflector. This time can be prolonged by use of motion in both transverse dimensions. In most cases of interest the betatron oscillation amplitudes induced during the turn-off of the perturbation are so small as to be negligible. Calculations made with the MURA IBM 704 computer, using the fields of the MURA 40 Mev two-way accelerator, demonstrated the feasibility of the method in alternating gradient accelerators, and accelerators with nonlinear restoring forces.

* Supported by the U. S. Atomic Energy Commission.

S4. Method of Increasing the Interaction Rate Density in Colliding Beam Accelerators.* KENT M. TERWILLIGER, *University of Michigan and Midwestern Universities Research Association.*—Fixed field accelerators can produce a beam density high enough for colliding beam experiments only if a large number of injected pulses are spatially superimposed; this number is limited in present designs by the energy difference—hence equilibrium orbit separation—of successively "stacked" pulses. Without this separation either the beam density could be increased or, with the same density, the beam dimensions and total beam current could be sharply reduced. A simple method which effectively achieves this[1] is the addition of a perturbing field of the form $H_z = a_M x \cos M\theta$, where x is the radial distance from a selected equilibrium orbit, and M is an integer close to ν_z. Until nonlinear effects set in, the forced oscillations of other close-by equilibrium orbits are proportional to their momentum difference, so they all can be made tangent or crossing at the target region. A perturbing field which produces tangent equilibrium orbits for a simple machine geometry has been designed using the MURA IBM 704 computer.

* Supported by the U. S. Atomic Energy Commission.
[1] A similar suggestion has been made independently by E. D. Courant.

S5. Helical Quadrupole Magnetic Focusing Systems.* LEE C. TENG, *Argonne National Laboratory.*—A. V. Crewe[1] pointed out that with air core and high field a helical quadrupole magnetic lens is easier to build than a conventional alternating sectional quadrupole focusing magnet system. The motion of a charged particle in such a helical quadrupole field is studied here under the linear paraxial approximation. The result shows that the focusing action of such a helical quadrupole system is about 10% stronger than that of a corresponding alternating sectional system with the same periodicity and field gradient. With appropriately chosen field gradient, pitch and length, a helical quadrupole magnet can be designed to form point images from point sources located on the axis. Formulas and graphs relating these parameters are derived. An example of a helical quadrupole lens system is shown. λ is the pitch of the helix. In the analogous case of alternating conventional lenses, within this distance there would normally occur two pairs of focus-defocus elements.

* This work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Private communication.

S6. The rf System for the Cambridge 6-Bev Electron Synchrotron.* K. W. ROBINSON, *Cambridge Electron Accelerator.*—In the design of the rf system for the Cambridge Accelerator, it is necessary to develop an rf accelerating voltage to make up the radiation loss of 4.5 Mev/turn and contain the quantum induced phase oscillations. The optimum frequency is in the uhf range and is chosen to be 475 Mc. At this frequency a peak rf voltage of 6 Mev/turn is calculated to be necessary to reach 6 Bev with small loss of particles from quantum induced phase oscillations. It is proposed to use 16 symetrically located rf cavities, which are strongly coupled together by wave guide so as to form a closed ring which behaves as a single resonant system. Each cavity will consist of two half-wave sections, partially loaded with re-entrant drift tubes. The measured shunt impedance including transit time factor is about 5 meg. The Q is about 20 000. The total peak power required with small beam loading is calculated to be 250 kw.

* Supported by the U. S. Atomic Energy Commission.

S7. The Design of the Cambridge Electron Accelerator rf System.* J. R. REES AND K. W. ROBINSON, *Cambridge Electron Accelerator.*—The design of the rf accelerating system of the Cambridge Electron Accelerator[1] is described. In order to choose the electrical parameters of the system so as not to incur excessive power losses due to inevitable mistunings, a perturbation calculation is used. The system comprises sixteen individual cavities each consisting of two resonant chambers and accelerating gaps. The two chambers are inductively overcoupled so as to split the cavity's two characteristic resonances about 100 band widths. Each chamber is 34 times overcoupled to a wave guide which connects to the next cavity around the accelerator. The electrical length of the wave guides linking the cavities is chosen so as to avoid an exact resonance on the line linking the cavities. The introduction of rf power into the circuit is discussed.

* Supported by the U. S. Atomic Energy Commission.
[1] K. W. Robinson (preceding abstract).

S8. *X*-Band Analog of the Cambridge Electron Accelerator rf System.* A. E. BARRINGTON, J. DEKLEVA, AND J. R. REES, *Cambridge Electron Accelerator.*—In order to gain practical experience on various problems arising from Robinson's proposal of the strongly coupled multicavity synchrotron rf system,[1] a simplified X-band wave guide analog was constructed. The work was undertaken in two stages, first a simple single-cavity ring and later a more complicated double-cavity ring. The present report comprises an account of the design of components and of methods of measurement for the two systems and experimental studies thereof. The experimental data obtained were in good agreement with the theoretical solutions.

* Supported by the U. S. Atomic Energy Commission.
[1] K. W. Robinson and J. R. Rees (preceding abstracts).

S9. Particle Orbits in Time-Dependent Axisymmetric Magnetic Fields. S. TAMOR, *General Electric Research Laboratory.*—Consider the motion of a charged particle in a magnetic field with $\omega(t) = eB(t)/mc$ an arbitrary function of time. We are particularly concerned with the case when $\dot{\omega}/\omega^2$ is not always small. If the field is spatially uniform over the volume explored by the particle, analytic solutions are obtained for the orbit for $\omega(t)$ of the form kt^n. Consider $n > -1$ and $\omega(-t) = \pm\omega(t)$ so that as $|t| \to \infty$, $\dot{\omega}/\omega^2 \to 0$. Defining the quantity $K = |\omega|(R^2 + \lambda^2)$ in terms of the instantaneous guiding center coordinate and cyclotron radius, we find $K(t \to -\infty) = K(t \to +\infty)$. This, combined with the conservation of generalized angular momentum, completely specifies the orbit as $t \to \infty$ in terms of the motion at $-\infty$ except for a phase. This connection is shown to be unchanged by the addition of a slowly varying perturbation to $\omega(t)$ which vanishes for large $|t|$, and hence defines a generalized adiabatic invariant. The implications of the result for particle acceleration in rapidly varying magnetic fields will be discussed.

S10. Pulsed 200-Kilogauss Magnet for Accelerator Experiments.† D. H. BIRDSALL AND H. P. FURTH, *University of California, Livermore.*—A 200-kilogauss pulsed air-core magnet system designed along principles previously described[1,2] has been constructed. The useful volume is 2 in. in diameter and

3 in. in length. The field remains within 1% of maximum for 50 μs. A 70 000 joule, 13.5-kv capacitor source is discharged at 55 ka. Most of the energy is dissipated in external low-inductance resistors, into which the magnet is short-circuited at current maximum. The rest is removed from the coil by dry ice and silicone oil cooling. Coil operation up to 5000 shots is considered safe, the mean life expectancy being about 7000. By using several magnets, a Bevatron run of 15 000 pulses at a repetition rate of 11/min was recently completed without equipment failure of any kind.

† This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] H. P. Furth and R. W. Waniek, Rev. Sci. Instr. **27**, 195 (1956).
[2] Furth, Levine, and Waniek, Rev. Sci. Instr. **28**, 949 (1957).

S11. Distribution of the Path Lengths of Particles of an Isotropic and Spatially Homogeneous Flux in a Cylindrical Detector.* GERHART GROETZINGER, PHILIP SCHWED, AND WAYNE RAY, *RIAS.*—In using a detector like an ionization chamber to investigate the nature of an isotropic spatially homogeneous flux of charged particles it is necessary to know the distribution of path lengths of particles in the detector in order to interpret the results. With a view toward the application of a detector with a sensitive volume of cylindrical shape such as is ordinarily applied for this purpose, we have computed from geometrical considerations the distribution of path lengths resulting when such a flux is incident upon a detector of this configuration. These calculations have been carried out for detectors of height h and diameter d over the range from $h/d=0.25$ to $h/d=3.0$. On either side of this range the distribution is essentially independent of h/d. As an example the average path length for $h=d$ is $0.63d$ and the standard deviation 54%. The distributions obtained will be presented.

* Work done with support of National Science Foundation under the IGY Earth Satellite Program.

S12. Characteristics of Boron and Fluorine Beams in Emulsions and Crystals.* P. G. ROLL, F. E. STEIGERT, AND A. M. SMITH, *Yale University.*—The range *vs* energy relationships in Ilford G-5 nuclear emulsions and the pulse height *vs* energy characteristics in thallium activated CsI crystals for beams of boron and fluorine have been determined. The particles were accelerated to 10 Mev/nucleon in the Yale Heavy Ion Linear Accelerator, magnetically analyzed, degraded in energy using nickel absorbers, reanalyzed, and detected. The resulting curves show the same general shapes as those previously obtained for carbon, nitrogen, and oxygen. Similarly, in the G-5 emulsions, the "taper" is again apparently a reliable label as to species. The range *vs* energy relationships for these and other species of heavy ions in nickel will be given.

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.

Invited Paper

S13. The Luminescent Chamber in High-Energy Physics. L. W. JONES, *University of Michigan.* (30 min.)

SATURDAY MORNING AT 9:30

Willard, Congressional Room

(L. M. BOLLINGER presiding)

Neutron Spectroscopy

SA1. The ORNL Neutron Fast Chopper Time-of-Flight Spectrometer. R. C. BLOCK, J. A. HARVEY, AND G. G. SLAUGHTER, *Oak Ridge National Laboratory.*—A new time-of-flight spectrometer has been recently installed at the 20-Mw Oak Ridge Research Reactor. This spectrometer consists of an 18-in. diameter rotor; a 180-m evacuated flight path with stations at 13, 45, and 180 m; banks of BF_3 proportional counters as detectors; and a 2048 channel magnetic core time analyzer. This equipment can be operated with either of two distinct rotors, the M1 and M2 rotors which have been designed for partial cross section and high resolution total cross section measurements, respectively. The M1 rotor previously has been described.[1] The M2 rotor is fabricated from age-hardened K-Monel and produces two neutron bursts per revolution from a tapered slit system. The slit system consists of 18 slits parallel to each other. Each slit is 0.045 in. wide at the center of the rotor and is tapered to 0.015 in. wide at the periphery of the rotor. The M1 rotor spinning at 6000 rpm and with a 45-m flight path has a resolution of 0.06 μsec/m and the M2 rotor spinning at 13 500 rpm has a designed resolution of <0.010 μsec/m with a 180-m flight path. Data which are now being taken with the M2 rotor will be presented.

[1] Slaughter, Block, and Harvey, Bull. Am. Phys. Soc. Ser. III, **3**, 177 (1958).

SA2. Analysis of the Low-Energy Neutron Resonances in Tungsten. J. E. EVANS, F. W. K. FIRK, B. B. KINSEY,* M. C. MOXON, J. R. WATERS, AND G. H. WILLIAMS, *Atomic Energy Research Establishment, Harwell.*—The Harwell 15-Mev electron linear accelerator has been used as a neutron source for a time-of-flight investigation of tungsten resonances. The width of the neutron pulse has been reduced from 1.25 to 0.25 μsec giving improved resolution. Path lengths varied between 10 and 32 m. Elastic scattering, neutron capture, and transmission experiments were made using methods described previously.[1] The results from these three experiments were combined by a least squares method to give values for the spin, radiation width, and neutron width of the levels up to 115 ev. For W^{183}, the 7.62, 27.1, 46.1, and 102 ev levels have spin 1, the 47.7 ev level has spin 0. Preliminary results show the average radiation width for W^{183} to be 52 ± 5 mev (4.14, 21.2 and 115 ev levels); that of the 18.8 ev resonance in W^{186}, about the same, and those for W^{184}, somewhat higher. Experimental details and final values of the parameters for the nine resonances observed will be presented.

* Now at The University of Texas.
[1] Evans, Kinsey, Waters, and Williams, Nuclear Phys. 9, 205 (1958).

SA3. Total Cross Section Measurements on Np^{237}.* J. E. CLINE, E. H. MAGLEBY, AND W. H. BURGUS, *Phillips Petroleum Company, Idaho Falls.*—The total cross section (for neutron interaction) of Np^{237} has been measured as a function of energy for neutrons of energy from 0.01 ev to 35 ev. This measurement entailed the use of the MTR fast chopper time-

of-flight spectrometer. Forty-six resonances have been observed in this energy region. The resolution of the instrument, when used with a 45-m flight path, was such that some of the resonances reported by Slaughter were seen as doublets and in some cases as triplets. Energies of the resonances were measured to be: 0.489, 1.325, 1.473, 1.975, 3.885, 4.282, 4.891, 5.810, 6.41, 6.73, 7.47, 8.36, 9.08, 9.31, 10.20, 10.85, 10.9, 11.1, 12.34, 12.73, 13.30, 13.76, 14.7, 16.3, 17.09, 17.81, 19.3, 20.1, 22.2, 22.6, 23.1, 23.9, 24.3, 24.9, 25.2, 25.7, 26.9, 27.5, 28.8, 30.7, 31.3, 31.7, 33.6, 34.1, and 35.1 ev. The accuracy of these energies are approximately 1%. The data from 0.1 to 9 ev were analyzed by the methods of "area analysis" and of "shape fitting" to obtain the resonance parameters. A plot of the number of levels below energy E *vs* E gave a constant slope of 1.52 levels/ev up to an energy of 32 ev. This gives a level spacing of 1.32 ev/spin state.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

SA4. Slow Neutron Cross Sections of Mercury Isotopes.* R. T. Carpenter and L. M. Bollinger, *Argonne National Laboratory.*—In order to study the dependence of the characteristics of nuclear levels on the proximity to a closed shell, the Argonne fast chopper has been used to measure the neutron total cross sections of the mercury isotopes. Measurements were made on four samples of normal mercury and six enriched samples. Resonances in Hg^{198} are seen at 23, 90, 302, 344, 418, and 967 ev; in Hg^{199} at 33.5, 130, 175, 263, 315, 492, 810, 884, and 1076† ev; in Hg^{200} at 1340, 2750, and 7800 ev; in Hg^{201} at 43, 210, 312, 445, 565, and 687† ev; In Hg^{202} at 271,† and 4130 ev. Resonances which are as yet unassigned are seen at 71, 93, 230, 352 380, 515, 650, 967, 1021, 1260, 1480, 1570, 1640, 1720, 1750, 1870, 2060, 2290, 2490, 3100, and 3800 ev. Small dips in the transmissions of the enriched samples are undoubtedly missed above approximately 400 ev. The expected increase in the radiation width and the level spacing as we approach the closed neutron shell is observed, although some anomolies are apparent. Resonance parameters and curves of Γ_γ and $2(2J+1)S$ *vs* A will be shown.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Tentative identification.

SA5. Neutron Resonances in Arsenic.* J. Rosen, S. Desjardins, W. W. Havens, Jr., and L. J. Rainwater, *Columbia University.*—The Nevis synchrocyclotron neutron velocity selector has been used to study the resonance structure of As in the region from 150 to 10 000 ev. With a resolution of 4 mμ sec/m essentially all resonances are resolved up to an energy of approximately 3 kev. The number of resonances observed in the energy regions 0–1, 1–2, 2–3 kev are 16, 12, and 15, respectively. This represents a considerable extension of the previously studied region.[1] Measurements were made by both self-detection, employing the radiative capture mode, and transmission, utilizing our newly operative B^{10}—NaI detector. The two methods complement each other and provide more information than is available from thick-thin transmission area measurements alone. The performance of the latter detector scheme will be described. Resonance parameters and their systematics will be presented.

* This work was partially supported by the U. S. Atomic Energy Commission.
[1] Coté, Bollinger, and LeBlanc, Phys. Rev. 111, 288 (1958).

SA6. Low-Energy Neutron Cross Sections of Fissionable Nuclei. Erich Vogt, *Atomic Energy of Canada Limited.*—A previous fit[1] to the data for the low-energy neutron cross sections for U^{235} is elaborated to explain the fact that α, the ratio of capture to fission, has peaks at the resonance energies. The anomalous behavior of α arises from the strong negative energy resonance of U^{235} which dominates the cross sections in between resonances and happens to have a low value of α. The question arises as to whether or not the other common fissionable isotopes have abnormal negative energy resonances. A detailed fit to the cross sections of Pu^{239} will be shown which requires a negative energy state with a reduced neutron width of moderate size interfering with only several of the first few positive energy resonances. The analysis of the data for U^{233} will also be discussed. It appears therefore, that the low-energy neutron resonances of the fissionable isotopes are not generally anomalous. Their interference can be used, in a simple way, to obtain information about the number of fission channels.

[1] E. Vogt, Phys. Rev. 112, 203 (1958).

SA7. Interpretation of Resonance Capture Measurements. J. D. Fox, M. K. Brussel, D. J. Hughes, and R. E. Chrien, *Brookhaven National Laboratory.*—Work on neutron resonance capture gamma rays is continuing with the Brookhaven fast chopper. Measurements of the neutron resonance capture gamma rays can be used to supplement and improve the parameters derived from total cross section data. For resonances in which the radiation width is nearly the total width, both the capture gamma rays and total cross sections yield the same information. When the radiation width is less than about half the total width, the capture measurements can be combined with the total cross section parameters $g\Gamma_n$ and Γ, determined by thin and thick target transmission experiments, to give accurate values of Γ, Γ_γ, and g in favorable cases. This method, applied to the 134-ev resonance in Ag^{109} indicates a g of $\frac{1}{2}$, in agreement with the interpretation of Rae *et al.*[1] In addition, the 102-ev level in W^{183} was found to have $g=\frac{1}{2}$. This was further established by identification of the ground-state gamma ray transition following neutron capture. This gamma ray would not have been present had the spin of the 102-ev level been 0.

[1] Rae, Collins, Kinsey, Lynn, and Wiblin, Nuclear Phys. 5, 89 (1958).

SA8. Total Neutron Cross Section of Ir^{191} and Ir^{193}.* H. H. Bolotin and R. E. Chrien, *Brookhaven National Laboratory.*—The BNL fast chopper and time-of-flight analyzer have been used to investigate the neutron transmission of iridium isotopes from thermal energies up to about 100 ev. Data obtained from several thicknesses of normal iridium and samples enriched in Ir^{191} and Ir^{193} will be presented. In this energy range 37 resonances were found, of which many have not been previously reported. Neutron widths and isotopic identification of these levels, as well as radiation widths for several resonances as obtained by the thin-thick area method, have been determined. Strength function determinations for both Ir^{191} and Ir^{193} from isotopic resonance parameters will be given and compared with the value for normal iridium obtained in the kilovolt region by the averaging technique. Measurements of isotopic thermal cross sections will also be presented.

* Under the auspices of the U. S. Atomic Energy Commission.

SA9. The Multiple Scattering of Neutrons at Resonances.* T. J. Kennett and L. M. Bollinger, *Argonne National Laboratory.*—The growing interest in the measurement of partial neutron cross sections has led to an increasing need for a quantitative method of considering the problem of multiple scattering of neutrons in the sample being studied. To fill this need a Monte Carlo program has been developed which can be applied to finite samples whose cross sections can be described by two Breit-Wigner single-level formulas. This program has been used to understand the nature of an experiment in which the capture rate for a thick sample of Mn was measured as a function of the time-of-flight of the incident neutron. The experimental results exhibited a marked peak in counting rate at 430 ev, an energy at which no resonance is observed in total cross-section measurements. This effect was also obtained

from the Monte Carlo calculation when only the known resonances were used to define the cross section. The calculated result showed that this peak was a direct result of multiple scattering. It appears that partial cross-section measurements are of questionable value when thick samples are used.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

SA10. Nuclear Level Density According to the Shell Model.* N. ROSENZWEIG, *Argonne National Laboratory.*—A practical method of direct enumeration has been devised for obtaining the features of the nuclear level density implied by the shell model. (The scope of the calculation envisioned is roughly equivalent to that considered by C. Bloch.)[1] The method enables one to study (1) the distance between excited configurations, (2) the special effects arising from an unusual level structure (closed shells, Fermi levels of an especially large or small degeneracy, gaps, etc.), (3) perturbations resulting from "pairing" and other residual interactions which are given as functions of the quantum numbers of the shell model, and (4) distribution of levels with respect to parity and spin. The method consists of solving a related combinatorial problem, the solution of which is applicable to the treatment of all nuclei. A set of "primitive configurations" is generated in which the exclusion principle and the actual number of particles are ignored. Then the structural details of particular nuclei are considered. The method, rather than specific results, will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] C. Bloch, Phys. Rev. 93, 1094 (1954).

SA11. Analysis of Neutron Resonances and Optical Model Calculations in O^{16}. E. H. AUERBACH, E. D. REILLY, JR., AND N. C. FRANCIS, *Knolls Atomic Power Laboratory.**—Earlier optical model calculations of low-energy neutron elastic scattering by O^{16} have required different potential wells for s wave and for higher l values.[1] These calculations are extended by using one Saxon-type real well with a spin-orbit term of the Thomas form. In addition to the earlier requirements that the well parameters give correct cross sections and O^{17} bound-state energies, agreement of polarization predictions with experiment[2] is also required. With the well parameters so determined, a single-particle resonance at 1 Mev and several core-excitation resonances are predicted and compared with experiment. The calculation is extended to higher energies by introducing a surface imaginary term in the potential; its strength is fixed by requiring that the angular distributions at 14 Mev agree with experiment and that the strength function be given correctly at 4 Mev. The effects of a volume imaginary term and of mixtures of surface and volume terms are considered.

* Operated for the U. S. Atomic Energy Commission by the General Electric Company.
[1] J. L. Fowler and H. O. Cohn, Phys. Rev. 109, 89 (1958).
[2] Striebel, Darden, and Haeberli, Nuclear Phys. 6, 188 (1958).

SA12. Optical Model Analysis of Low-Energy Neutron Polarization in Zirconium and Neighboring Elements. E. D. REILLY, JR., E. H. AUERBACH, AND N. C. FRANCIS, *Knolls Atomic Power Laboratory.**—Experimental evidence indicates that p-wave effects for neutron scattering in the kev region reach a maximum at about $A=91$. Spin-orbit optical model calculations have been performed on a high-speed digital computer using parameters consistent with this mass and energy range. Broad peaks have been found in the total cross section, p-wave strength function, asymmetry ratio $\sigma(180°)/\sigma(90°)$, and polarization, all as a function of A. Agreement with experiment is quite good except that calculated polarizations near the p-wave peak are of the order of 80%, in contrast to experimental values of about 20%. But since the element at this peak, zirconium, is a mixture of isotopes, it is proposed that polarization measurements performed on separated Zr^{91} might result in much higher values than those found for natural zirconium. Predictions will be given, as a function of A, for the location in energy of the p-wave maxima where high polarizations may be expected experimentally.

* Operated for the U. S. Atomic Energy Commission by the General Electric Company.

SA13. Capture of p-Wave Neutrons in Zr. T. J. KRIEGER, N. C. FRANCIS, AND R. M. ROCKMORE, *Knolls Atomic Power Laboratory.**—The utility of the direct-interaction model in the calculation of neutron capture cross sections by complex nuclei has been demonstrated[1] for the case of the capture of s-wave neutrons by Pb^{207}. However, in other cases, the possibility of compound nucleus formation complicates the problem. In the kev region, Zr is of particular interest in this respect since the neutron p waves can enter the nucleus at relatively low energies where the compound nucleus contribution is still strong and there are d states to which the neutrons may go in E-1 transitions. In the direct-interaction calculation, both the continuum and bound-state wave functions are generated with spin-orbit coupling. Predictions are made for the dependence of the cross section on the energy of the neutron and for the different isotopes of Zr. It is found that the compound nucleus and direct-interaction p-wave contribution to the (n,γ) cross sections are both proportional to the incident neutron's momentum at low energies but the compound nucleus contribution drops more rapidly than the direct cross section contribution at high energies, the direct-interaction and compound nucleus cross sections going as $E^{-\frac{1}{2}}$ and E^{-1}, respectively.

* Operated for the U. S. Atomic Energy Commission by the General Electric Company.
[1] A. V. Shut'ko and D. F. Zaretskii, Soviet Phys. JETP 2, 769 (1956).

SATURDAY MORNING AT 9:00

Departmental Auditorium

(W. K. H. PANOFSKY presiding)

Muons and Pions

T1. The g Factor of the μ Meson.* R. L. GARWIN,† D. D. HUTCHINSON, S. PENMAN, AND G. SHAPIRO, *Columbia University.*—The magnetic moment of the mu meson has been measured, using a stroboscopic technique, to an accuracy of 6.6×10^{-4}.[1] The ratio of the muon precession frequency to that of a proton in the same magnetic field was measured to be 3.1845 ± 0.0002. Electrodynamics predicts the g factor ($g=e/2\mu mc$) of a Dirac particle to be 2(1.00116). A determina-

tion of the value of g to an accuracy comparable to that of the moment requires a better knowledge of the mass than exists today. A well-defined lower limit does exist from the study of mesic atom levels.[2] The uncertainties in this mass limit are probably much smaller than the literature indicates. Tentative results with an approximate assignment of errors to the mass limit combined with a small adjustment in its value from a recalculation of the vacuum polarization leads to a value of g which is in serious disagreement with theory.

* This work was supported by the Office of Naval Research and the U. S. Atomic Energy Commission.
† Also with IBM Watson Laboratories.
[1] Garwin, Hutchinson, Penman, and Shapiro (submitted to Phys. Rev. Letters).
[2] Koslov, Fitch, and Rainwater, Phys. Rev. 95, 291 (1954).

T2. Search for the Decay Mode $\mu^+ \to e^+ + \gamma$. H. F. DAVIS, A. ROBERTS, AND T. F. ZIPF, *University of Rochester*.—The occurrence of the decay mode $\mu^+ \to e^+ + \gamma$ is of great interest with respect to the possible existence[1] of an intermediate heavy vector boson. A search for this decay mode has been conducted with the University of Rochester cyclotron. A beam of 32-Mev π^+ mesons is stopped in a carbon target. μ^+ mesons from the decay of the π^+ meson also stop in this target. The decay mode $\mu^+ \to e^+ + \gamma$ is looked for with positron and γ-ray telescopes that lie along a line approximately perpendicular to the incident π^+-meson beam. The γ-ray telescope is calibrated with γ rays from the capture of slow π^- mesons in liquid hydrogen. The positron telescope is calibrated with both 55-Mev positrons and with the continuum of positrons from the normal μ decay. The observable upper limit for the abundance of this decay mode is set by the background coincidence rate. A preliminary upper bound of 10^{-5} has been found[2] and additional data are being obtained.

[1] G. Feinberg, Phys. Rev. 110, 1482 (1958).
[2] Phys. Rev. Letters (to be published).

T3. Bohr-Orbit Binding Effects in Muon Decay.* J. W. KEUFFEL AND L. GAIL DESPAIN, *University of Utah*.—An experiment is in progress to measure the spontaneous decay rate λ_d of negative muons, i.e., the decay rate which would be directly observed if the nuclear capture process could be shut off. Since the initial rate of decay electrons from the target is given by $r = k\lambda_d N$, where k is the detection efficiency and N the number of μ^- stopping in the target, λ_d may be obtained from the electron decay curve extrapolated to zero time. Counting rates of about 2000 μ^+ per day (or 200 μ^- in Fe) have been obtained with the apparatus, an improvement of about a factor of 6 over the apparatus previously described.[1] A very large scintillator is used to detect a good fraction of the shower produced by a decay electron deep in the target; the energy resolution of the shower detector permits us to bias against small (<8 Mev) events due to muon capture γ rays without loss of many electron counts. Measurements are being made on a group of elements in the neighborhood of Fe to determine the shape of the λ_d *vs* Z curve. For Fe, λ_d is actually about 20% greater than the decay rate of the free muon, a result which so far has received no theoretical interpretation. Results will be reported.

* Assisted by the National Science Foundation.
[1] F. E. Holmstrom and J. W. Keuffel, Bull. Am. Phys. Soc. Ser. II, 3, 408 (1958).

T4. Experimental Tests of the Fermi-Teller Z Law.* G. BACKENSTOSS, B. BLOCH, B. CHIDLEY, R. REITER, T. ROMANOWSKI, R. SIEGEL, AND R. SUTTON.—Experiments to test the validity of the Fermi-Teller "Z law"[1] have been performed in LiI, AgCl, and UF_4. Negative μ mesons were stopped in targets of these materials and decay electrons were detected by a scintillation counter telescope. The times of detection of the electrons with respect to the μ mesons were measured by means of a time interval meter. After background subtraction, the decay curves, characteristic of decay of μ mesons captured by Li, Cl, and F, were used to obtain the fraction of μ mesons captured by these elements. The efficiency of the counters was determined geometrically and by measurements using a carbon target. The measured ratios of meson capture by the elements in the compounds were iodine to lithium 1.3 ± 0.5, silver to chlorine 0.8 ± 0.2, and uranium to fluorine 0.7 ± 0.3, where the standard deviations include estimates of systematic errors. These results indicate violations of the Z law similar to those observed in the extensive measurements of Sens *et al.*[2]

* Supported in part by the U. S. Atomic Energy Commission.
[1] E. Fermi and E. Teller, Phys. Rev. 72, 399 (1947).
[2] Sens, Swanson, Telegdi, and Yovanovitch, Nuovo cimento 7, 536 (1958).

T5. π^+ Photomeson Production from Hydrogen near Threshold. J. E. LEISS AND S. PENNER, *National Bureau of Standards*.—Previous data[1,2] on photomeson production from hydrogen from threshold to 180 Mev obtained by counting the positrons from μ^+ decay have been reanalyzed. The corrections applied are: (a) more accurate μ decay spectrum, (b) corrected betatron energy scale, (c) better knowledge of x-ray monitor calibration, (d) use of Bethe-Heitler bremsstrahlung theory with Davies-Bethe-Maximon correction rather than Schiff theory, and (e) correction for decay positron annihilation in flight in the counter telescopes. With these corrections applied our data are in good agreement with the theoretical cross-section energy dependence. The meson-nucleon coupling constant derived from our data is $f^2 = 0.080 \pm 0.007$, in good agreement with scattering experiments. The cross section at 160 Mev is in excellent agreement with recent plate data.[3]

[1] Leiss, Penner, and Robinson, Phys. Rev. 98, 1188 (1955).
[2] S. Penner and C. S. Robinson, Bull. Am. Phys. Soc. Ser. II, 1, 173 (1956).
[3] Barbaro, Goldwasser, and Carlson-Lee, Bull. Am. Phys. Soc. Ser. II, 4, 23 (1959).

T6. Photoproduction of π^0 from Hydrogen in the Region of 900/1200 Mev.* H. E. JACKSON, J. W. DEWIRE, AND R. M. LITTAUER, *Cornell University*.—Measurements of the absolute differential cross section for single π^0 production from hydrogen have been extended to the interesting region of 950 to 1140 Mev[1,2] using the bremsstrahlung beam of the Cornell synchrotron. To date, excitation curves for center-of-mass angles $\overline{90}°$ and $\overline{50}°$ have been measured. The recoil proton is counted in a counter telescope in coincidence with a γ ray from the π^0 decay observed in a total absorbing Čerenkov counter. Because of prohibitively high nuclear absorption corrections the proton ranges were not determined. Instead the proton angle and the incident γ-ray energy were measured, the mean incident γ ray being determined by a subtraction technique. The results represent average differential cross sections over 100-Mev intervals. Preliminary results indicate a $\overline{90}°$ cross section which decreases monotonically from 1.7 ± 0.2 μb/sterad at 950 Mev to 0.9 ± 0.2 μb/sterad at 1140 Mev while the $\overline{50}°$ data show an increase from 1.4 ± 0.15 μb/sterad at 950 Mev to 1.95 ± 0.15 μb/sterad at 1050 Mev. Measurements are being continued at backward center-of-mass angles.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] I. P. Dixon and R. L. Walker, Phys. Rev. Letters 1, 458 (1958).
[2] H. C. Burrowes *et al.*, Phys. Rev. Letters 2, 119 (1959).

T7. Photoproduction of Negative Mesons from Deuterium.* D. H. WHITE, B. M. CHASAN, G. COCCONI, V. T. COCCONI, AND R. M. SCHECTMAN, *Cornell University*.—A 24-in. diffusion cloud chamber filled to 15 atmos with tritium-free deuterium gas,[1] operating in a magnetic field of 6 k gauss, has been placed in the 1050-Mev "hardened" bremsstrahlung beam of the Cornell synchrotron. Events of the type $\gamma + D \to p + p + \pi^-$ have been observed and analyzed. The momenta and the angles of all the secondary particles are determined, as well as the energy of the incoming photon. The distribution of the low-energy protons is compared to the calculated nucleon

momentum distribution in the deuteron as predicted by the spectator model.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] The deuterium gas with tritium-to-deuterium ratio 6×10^{-18} was supplied by the isotope division of the Oak Ridge National Laboratories.

T8. Ratio of π^-/π^+ Photoproduction from Deuterium.* G. NEUGEBAUER, W. WALES, AND R. L. WALKER, *California Institute of Technology.*—Additional data have been obtained on the angular distribution and energy dependence of the ratio of negative-to-positive pions produced in a liquid deuterium target by the bremsstrahlung beam of the Caltech Synchrotron.[1] These data extend the measurements previously reported to backward angles so that the data now include laboratory angles from 10° to 140° and laboratory pion momenta from 250 Mev/c to 950 Mev/c. For free nucleons this corresponds to center-of-momentum angles from 20° to 150° and effective photon energies from 500 to 1000 Mev. At 120° in the center of momentum system the ratio π^-/π^+ rises from 1.3 near threshold[2] to a peak of 1.7 at an effective photon energy of 550 Mev after which it drops to 0.5 at 1000 Mev.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] Neugebauer, Wales, and Walker, Bull. Am. Phys. Soc. Ser. II, 4, 23 (1959).
[2] Sands, Teasdale, and Walker, Phys. Rev. 95, 592 (1954).

T9. Photopion Production from Deuterium and the π^-/π^+ Ratio.* JOHN D. ANDERSON, DUANE C. GATES, THOMAS L. JENKINS, ROBERT W. KENNEY, AND WILLIAM P. SWANSON, *University of California, Berkeley.*—The reactions $\gamma+D\rightarrow\pi^-+2P$ and $\gamma+D\rightarrow\pi^++2N$ have been studied near threshold by observing 2- and 3-prong stars and $\pi^+\rightarrow\mu^++\nu$ decays, respectively, in the 4-in. deuterium bubble chamber placed directly in a 200-Mev hardened bremsstrahlung beam from the Berkeley synchrotron. Preliminary total cross sections, approximately corrected for chamber geometry, are given in Table I. The preliminary value $\sigma_{\pi^-}/\sigma_{\pi^+}=1.6\pm0.3$ was obtained for stopping mesons with a laboratory energy distribution 6.4 ± 2.7 Mev and an approximately isotropic laboratory angular distribution. The negative meson events have a measured photon-energy distribution 163 ± 8.6 Mev. Improved data on cross sections will be presented, including angular and energy distributions of the proton recoils. We wish to thank Professor Luis W. Alvarez and the bubble-chamber group for the use of the 4-in. bubble chamber.

TABLE I.

k(Mev)	σ_{π^-} (μbarns)
150 to 155	11 ± 4
155 to 160	33 ± 7
160 to 165	51 ± 11
165 to 170	39 ± 9
170 to 175	55 ± 6

* This work was done under the auspices of the U. S. Atomic Energy Commission.

T10. Proton-Proton Interactions at 970 Mev. A. P. BATSON,* B. B. CULWICK, J. G. HILL, AND L. RIDDIFORD, *University of Birmingham, England.*—A diffusion cloud chamber in a magnetic field has been used to study proton-proton interactions at 970 Mev. The results from 273 events of type $p+p\rightarrow n+p+\pi^+$, and 72 events of type $p+p\rightarrow p+p+\pi^0$, have been calculated in detail. The energy spectra of all particles, and the Q-value distributions between pairs of particles, are compared with the predictions of the isobar theory,[1] in which it is postulated that pion production proceeds through an intermediate state of isotopic spin $T=\frac{3}{2}$. The results for positive pion production are in agreement with this hypothesis, and disagree markedly with the predictions of a purely statistical theory. The neutral pion production data do not agree with the predictions from the isobar theory.

* Now at the University of Virginia.
[1] S. J. Lindenbaum and R. M. Sternheimer, Phys. Rev. 105, 1874 (1957).

T11. Scattering of 312-Mev Positive Pions by Hydrogen.* ERNEST H. ROGERS, HERBERT M. STEINER, CLYDE WIEGAND, TOM YPSILANTIS, OWEN CHAMBERLAIN, AND WILLIAM B. JOHNSON, *University of California, Berkeley.*—A counter experiment designed to measure the differential cross section for elastic π^+-p scattering has been performed. The pion beam, produced by bombarding a polyethylene target with the external proton beam of the 184-in. cyclotron, was focused and momentum-analyzed twice. A liquid hydrogen target was placed at the second focus, while an absorber at the first focus stopped the proton component of the beam. The mean energy of scattering was 312 Mev, with an rms energy spread of ±9 Mev. The beam incident upon the hydrogen target was monitored by an ion chamber. Scattered pions were detected by a counter telescope consisting of two scintillation counters and one Cherenkov counter. It was possible to count the conjugate protons in coincidence in only an extremely limited range of pion-scattering angles. Measurements were made at sixteen angles from 25° to 160° (lab) with statistical counting errors of ~3%. The rms angular resolution of the system was ~2°. Relative laboratory-system differential cross sections at some typical lab scattering angles are: 24.9°, 426±8; 44.5°, 187±4; 62.7°, 64.8±1.9; 88.2°, 27.7±1.1; 131.0°, 41.0±1.6; 159.2°, 47.0±1.7.

* Work done under the auspices of the U. S. Atomic Energy Commission.

T12. Polarization of the Recoil Proton in π^+-p Scattering at 312 Mev: Method and Apparatus.* OWEN CHAMBERLAIN, JAMES H. FOOTE, ERNEST H. ROGERS, HERBERT M. STEINER, CLYDE WIEGAND, AND TOM YPSILANTIS, *University of California, Berkeley.*—A counter experiment has been performed at the Berkeley 184-in. synchrocyclotron in which the polarization of the recoil proton in π^+-p scattering has been measured as a function of center-of-mass scattering angle in the region of 113.5° to 145°. The high-intensity positive pion beam necessary for this experiment was produced by the regenerated 740-Mev proton beam striking a 19-in.-thick CH_2 target. Pions produced in the forward direction were momentum analyzed and focused by a series of two bending and three quadrupole focusing magnets. A beam of 1×10^6 pions per second was incident upon a 1-g/cm²-thick liquid hydrogen target. The mean energy of scattering at this target was 312 Mev. Scintillation counters defined the direction of the recoil protons and counted the conjugate π mesons. The recoil protons were scattered by a carbon target, with an average proton scattering energy varying with recoil angle from 110 to 140 Mev, and their polarization analyzed by measuring the asymmetry produced in this scattering. Further counters detected this asymmetry. A proton beam of known polarization was used to determine the analyzing ability of the counter system.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

T13. Polarization of the Recoil Proton in π^+-p Scattering at 312 Mev: Results.* JAMES H. FOOTE, ERNEST H. ROGERS, HERBERT M. STEINER, CLYDE WIEGAND, TOM YPSILANTIS, AND OWEN CHAMBERLAIN, *University of California, Berkeley.*—The tentative results from the counter experiment measuring the polarization of the recoil proton in π^+-p scattering at 312 Mev are given in Table I. Here ϵ is the asymmetry produced by the recoil protons scattering off the carbon analyzing target; P_2 is the analyzing ability of the apparatus, and was determined by allowing a proton beam with a polarization of 0.75 to impinge upon the counter system under conditions corresponding to

TABLE I.

Center-of-mass scattering angle	ϵ	P_1	$P_1=\epsilon\bar{P}_1$
113.5	$+0.015\pm0.021$	0.357 ± 0.047	$+0.042\pm0.060$
123.5	-0.101 ± 0.030	0.554 ± 0.043	-0.182 ± 0.057
133.5	-0.084 ± 0.018	0.459 ± 0.044	-0.183 ± 0.043
145	-0.078 ± 0.019	0.531 ± 0.017	-0.147 ± 0.036

those in the recoil proton case; P_1 is the polarization of the recoil protons. Errors given are statistical only. The sign of the polarization is said to be positive when a preponderance of the recoil protons have their spins pointing the direction of $\mathbf{p}_i\times\mathbf{p}_f$, where this quantity is the cross product of $\mathbf{p}_i$, the initial momentum vector of the π meson, and $\mathbf{p}_f$, the *final* momentum vector of the π *meson*.

* Work done under the auspices of the U. S. Atomic Energy Commission.

T14. Charge Exchange Scattering of 128-Mev Negative Pions.* C. M. YORK, C. O. KIM, W. KERNAN, AND E. L. GARWIN, *The University of Chicago*.—The charge exchange scattering of negative pions on liquid hydrogen has been measured at 128 ± 2 Mev. A lead glass Čerenkov counter was used to measure the gamma-ray spectra from the decay of the neutral pions. These spectra were measured at 45°, 80°, 116°, and 135° relative to the incident beam. The data are used to determine both the angular distribution of the neutral pions in the center of mass system, and the value of the cross section. The results will be discussed.

* Research supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

T15. Charge Symmetry and Pion Scattering at 500 Mev. J. BALLAM* AND J. HUANG, *Michigan State University*, AND J. H. SCANDRETT AND W. D. WALKER,† *University of Wisconsin*.—The angular distributions from $(\pi^+$-$p)$ and $(\pi^-$-$n)$ scattering have been compared at approximately the same pion energies (500 Mev). The π^- data were obtained by observing the number of deflections of incoming pions in a propane chamber and the π^+ data were obtained from Willis[1] who used a hydrogen bubble chamber. The comparison was made by modifying the π^+ data by the Fermi momenta of protons in a carbon nucleus and by adding the effect of the diffraction of the pions. This modified distribution is compared with the deflection data at large angles (>32 deg) where the diffraction is small as well as at the smaller angles. The curves agree quite well although the fit is better at the larger angles.

* Supported in part by a grant from the National Science Foundation.
† Supported in part by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] W. J. Willis, thesis, Yale University.

T16. On the Electron-Photon Cascade of a High-Energy π^0 Observed in Nuclear Emulsion.* MARTIN W. TEUCHER, D. M. HASKIN, E. LOHRMANN, AND MARCEL SCHEIN, *University of Chicago*.—The electron-proton cascade of one high-energy π^0 originating in a nuclear interaction of type $6+16_p$ [1] could be followed 22 cm through a stack of nuclear emulsion. The longitudinal and lateral development of the cascade was investigated by mapping all electrons after 1, 2.4, 4, 5.5, and 7 cascade units. After 7 cascade units more than 5000 electrons could be counted. At this distance they are resolvable even in the central core. This makes a study of the lateral density distribution possible which can be compared with theory. The energy of the π^0 can thus be estimated to be between 10^{13} and 10^{14} ev which is well within the range of extensive air showers.

* Supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission, and by the National Science Foundation.
[1] Ballam, Huang, Scandrett, and Walker, Bull. Am. Phys. Soc. Ser. II, **4**, 275 (1959), preceding abstract.

SATURDAY MORNING AT 9:30

National Bureau of Standards, East Building

(CONYERS HERRING presiding)

Solid-State Theory

TA1. Surface States in a Finite One-Dimensional Lattice.* H. A. BROWN, *University of Miami*.—Using a method similar to Kramers'[1] treatment of the one-dimensional repetitive potential, a finite one-dimensional lattice of N atoms is considered. By continuity conditions, the wave function in successive cells is generated by means of a 2×2 matrix, M, whose elements are known in terms of the values of the even and odd solutions in one cell and their derivatives evaluated at the edge of the atomic cell. For a given potential, these elements are functions of the energy only. The electron probability density in the nth cell is obtained in terms of the matrix elements of M^n, which is found from a recurrence formula for M, and a surface is defined as one for which the probability density increases monotonically away from the center of the lattice. It is then easy to obtain the following results already found by Shockley[2] by means of a somewhat different procedure: As an adiabatic compression from infinite separation is carried out and the atomic levels spread out into bands, no surface states occur until bands cross, after which they occur in pairs for large enough N. Furthermore, the larger the value of N, the closer in energy do the pairs lie.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] H. A. Kramers, Physica **2**, 483 (1935).
[2] W. Shockley, Phys. Rev. **56**, 317 (1939).

TA2. Correlation Function Method for Transport Phenomena.* H. MORI, *Brown University*.—Transport phenomena consist of two coupled relaxation processes; one is the macroscopic process of attaining spatial uniformity, whereas the other is the microscopic process of attaining internal equilibrium in small volume elements.[1] On this basis, an expression for the nonequilibrium density matrix will be derived in terms of dynamical fluxes. Consider a steady state of the lattice thermal conduction in nonmetallic solids, whose local equilibrium distribution is denoted by ρ_l. The density matrix of the system, ρ, which deviates from ρ_l, is determined with

$$\rho=\lim_{\tau\to\infty}\frac{1}{\tau}\int_0^\tau \rho_l(s)ds,$$

where $\rho_l(s)$ is the auxiliary density matrix of the system obtained if the system has started from an initial state $\rho_l(0)$. The distribution $\rho_l(0)$ is chosen to be ρ_l so that $\rho_l(s)$, $0<s<\infty$, is determined with the Hamiltonian of the system excluding the interactions with the surroundings provided that the size of the system is infinite. Thus the right-hand side can be evaluated. The treatment can be extended to nonsteady systems.

* Supported in part by the U. S. Air Force.
[1] H. Mori, Phys. Rev. **112**, 1829 (1958).

TA3. Simplified Approach to Correlation in a Degenerate Electron Gas.* JOHN J. QUINN AND RICHARD A. FERRELL, *University of Maryland.*—The ground state of a degenerate electron gas can be thought of as a reference or vacuum state which has definite electrostatic properties defined by a wave number and frequency dependent dielectric constant $\epsilon(\mathbf{k},\omega)$. Quasi-particle excited states can be constructed from this vacuum state by adding electrons or holes along with their polarization clouds. The energy of an excited state consists of both the individual energies of the quasi-particles[1] and their mutual energies of interaction. The latter can be computed from the screened Coulomb interaction. Following Landau,[2] one can use this approach in calculating the effective mass, spin susceptibility, compressibility, and separation energy. The effective mass yields Gell-Mann's[3] correlation correction to the specific heat.

* Work supported in part by the Office of Naval Research.
[1] J. J. Quinn and R. A. Ferrell, Phys. Rev. 112, 812 (1958).
[2] L. D. Landau, Soviet Phys. JETP 3, 920 (1957).
[3] M. Gell-Mann, Phys. Rev. 105, 369 (1957).

TA4. Electron Bands of a One-Dimensional Random Alloy.* JOHN S. FAULKNER† AND JAN KORRINGA, *The Ohio State University.*—Our model consists of a linear array of square wells, α and β, with two different well depths, equally spaced in a "random" sequence, with specified concentrations. Scattering of electrons with energy E by one well is characterized by a 2×2 matrix, A or B, expressing traveling waves on one side in terms of those on the other side. Scattering by a sequence of N wells is thus given by a product of N matrices, $ABBAB\cdots$. A random sequence of given concentration is represented by the average of all matrices obtained by permutations of this product. We have shown that the Nth root of this matrix is equal to the sum of our A and B matrices multiplied by energy dependent parameters that may be calculated for fixed N. Diagonalizing, we obtain an average reduced wave number k as a function of E.

* Supported by the U. S. Air Force Office of Scientific Research.
† Dupont Fellow.

TA5. Plane Wave Expansions in Energy Band Calculations. P. MARCUS AND H. SCHLOSSER, *Carnegie Institute of Technology.*—The calculation of energy eigenvalues in a periodic potential has been examined by direct expansion of the eigenfunction in symmetrized plane waves to high order. For a given potential, the matrix elements between symmetrized plane waves are formed, and the resulting secular equation is solved, by a single program on the IBM 704 electronic digital computer. The convergence of the eigenvalues of interest is examined as a function of the order n of the secular equation. At points of S character, the asymptotic deviation from the correct eigenvalues is of order $1/n$; at other points the deviation is of higher order. Calculations have been made on lithium, with two standard potentials, at the Γ_1, Γ_{15}, N_1, and N_1' points of the Brillouin zone using up to 40 symmetrized plane waves (equivalent to 1055 ordinary plane waves at the Γ_1 point). Extrapolation at these points to the limit $1/n=0$, gives satisfactory checks with previous calculations; at Γ_1 the agreement is within 0.3%. Extensions of these calculations to sodium and the application of a new variational formulation to a wave function expanded in both plane waves and spherical waves, each in the appropriate parts of the lattice cell, are in progress.

TA6. Modified Tight-Binding Method. FRANK STERN, *United States Naval Ordnance Laboratory.*—When overlaps between neighboring atomic wave functions $\psi(\mathbf{r})$ in a crystal are small, the tight-binding Bloch wave functions $\Psi(\mathbf{k},\mathbf{r})=\Sigma\exp(i\mathbf{k}\cdot\mathbf{r}_l)\psi(\mathbf{r}-\mathbf{r}_l)$ give good one-electron energies. In the $\mathbf{r}_l=0$ cell we expand the overlap contribution $[\Psi(\mathbf{k},\mathbf{r})-\psi(\mathbf{r})]$ in powers of $\mathbf{r}$, orthogonalize to the core, and add $\psi(\mathbf{r})$. With this modified form of the tight-binding wave function,[1] energy calculations (except exchange) are made in a single lattice cell and no longer require the multicenter integrals that usually arise.[2] The wave function is easily visualized when the wave vector $\mathbf{k}$ lies along a direction of high symmetry, since one or two coefficients in the expansion of the overlap contribution are then sufficient to characterize the energy and the charge density of the state. An example from the $3d$ band of metallic iron illustrates the tendency of states of low energy to have smoother charge distributions than do states of higher energy. This should be considered in calculating atomic scattering factors for transition metals with partially filled $3d$ bands.

[1] F. Stern, Ph.D. thesis, Princeton, 1955 (unpublished).
[2] P.-O. Löwdin, Advances in Phys. 5, 1 (1956).

TA7. Penetration of Transient Electromagnetic Fields into a Conductor. A. GRUMET, *Republic Aviation Corporation* (introduced by J. L. Neuringer).—The case of a uniform electric field, infinite in extent, abruptly applied to the plane face of a semi-infinite conductor, is considered. The current amplitude as a function of distance into the conductor and of time is then determined for different conductivities. The time element and distance for ignoring the displacement current term is determined. Finally the time and space nature of the applied electric field at distances far removed from the face of the semi-infinite conductor is considered.

TA8. Electromagnetic Properties of Insulators.* VINAY AMBEGAOKAR AND WALTER KOHN, *Carnegie Institute of Technology.*—We have studied a model of an insulator in which the nuclei are taken as fixed and the interaction between electrons is taken into account to all orders of perturbation theory.[1] The response of this insulator to an arbitrary electromagnetic distrubance of sufficiently long wavelength and low frequency was calculated from the complete Schroedinger equation, making use of linked cluster perturbation expansions. In this way the macroscopic Maxwell equations, containing the static dielectric constant and magnetic susceptibility were explicitly derived. We have also studied the electromagnetic properties of an insulator containing a single "free" carrier. These properties involve the "true" effective mass of the carrier, which includes the effects of electron-electron interaction.

* Supported in part by the Office of Naval Research.
[1] W. Kohn, Phys. Rev. 105, 509 (1957); *ibid.* 110, 857 (1958).

TA9. Brillouin Zone Face Critical Points in Face Centered Cubic Lattice Vibrations. WILLIAM C. OVERTON, JR., *U. S. Naval Research Laboratory.*—Critical points of a type not previously discussed in the literature are found on the hexagonal zone face for the two-force constant central-force model of the f.c.c. lattice. These points lie on lines on intersections of the faces with {110} planes. The surfaces of constant frequency near these points, which we denote as Q_+ and Q_- types, are given by $\nu^2-\nu_0^2=\pm A\eta+C\eta\zeta-D\eta^2+E\xi^2-F\xi^2$, where ν_0 is the frequency of the surface through the critical point and A, C, etc., are obtained by Taylor's expansion about the point. The localized coordinates, ξ and ζ lie in the zone face while η lies in {110} planes and is parallel to ⟨111⟩. The contributions to the frequency distributions, $\Delta G^+(\nu)$ and $\Delta G^-(\nu)$, have been obtained from analysis of the surfaces. The integrals in this analysis can be evaluated exactly in terms of well-known functions. Comparison of the results with machine calculations[1] of the vibration spectra shows good agreement.

[1] W. C. Overton, Jr., *Proceedings of the Fifth International Conference* (University of Wisconsin Press, Madison, 1958), p. 439; Naval Research Laboratory Report No. 5252 (Febraury, 1959).

TA10. Interfacial Curvature as a Design Factor in Metal-Dielectric or Metal-Semiconductor Barrier Contacts. ROBERT D. BARNARD AND SELBY M. SKINNER, *Case Institute of*

*Technology.**—The steady state conduction-diffusion equation characterizing the flow of single (majority) charge carriers in dielectrics with circular cylindrical boundaries, when rigorously solved,[1] yields a dependence of field strength in the dielectric upon the curvature of the bounding interface, as well as upon the nature and appropriate energy levels of the materials in contact. The rigorous solutions are obtained, but for convenience are expanded in terms of an unperturbed electrostatic state,[2] and higher order terms with current as the perturbation parameter. All electrical quantities and the resulting radial electrical field stresses are evaluated. Given materials of known electrical (energy) characteristics, the curvature of the interface provides a parameter which can be adjusted to achieve zero charge transfer and zero electromechanical stresses at the junctions. The dependence of rectification characteristics on the curvature of the dielectric interface is presented quantitatively.

* With the support of the Office of Ordnance Research.
[1] R. D. Barnard and S. M. Skinner, J. Electrochem. Soc. **105**, 55 (1958).
[2] S. M. Skinner and B. Carnahan, Bull. Am. Phys. Soc. Ser. II, **1**, 292 (1956).

TA11. Transmission Coefficients of Sound at a Quartz-Cubic Single Crystal Interface. ROBERT A. ARTMAN,* *Ford Motor Company and Bucknell University,* AND DAVID LARSON.†—The problems associated with the pulsed ultrasonic technique of measurement of the elastic constants of single crystals reported earlier[1] is extended to include cubic crystals oriented off pure mode directions. The solution is restricted to propagation directions on the boundary of the crystallographic unit triangle. The solution for reflection and transmission coefficients of a *BT*-cut quartz transducer coupled to a cubic single crystal has been determined. Curves of the six coefficients *vs* orientation for both sodium and beta-brass samples have been computed. The amplitude of the desired quasi-shear mode is large enough for measurement purposes. The undesired quasi-longitudinal mode can be as large as 55% of the incident in sodium. The amplitude of the pure shear mode never exceeds 1% of the incident. The angle between propagation direction and energy flux vector as a function of orientation has been computed. Strict attention must be given to orientation, since the energy flux vector can deviate from the propagation direction by as much as 60°.

* Now at Bucknell University.
† Deceased.
[1] R. A. Artman, Bull. Am. Phys. Soc. Ser. II, **4**, 158 (1959).

TA12. Modification of the Fokker-Planck Equation for Nonlinear Friction.* ARMUND SIEGEL, *University of Michigan and Boston University.*—Moyal's expansion[1] of the collision operator of the linear Boltzmann equation gives the exact basis of the Fokker-Planck equation. This expansion was studied relative to a simple model, involving one-dimensional motion of particles of mass M in a dilute gas of molecules of mass m ($M \gg m$), in internal equilibrium ("Rayleigh model"). The Fokker-Planck equation (=Brownian motion approximation) for the distribution of particle velocities V is obtained by breaking off the Moyal expansion after the second term, and taking the two retained "derivate moments" only to lowest order in V; this means taking the Döppler friction (first derivate moment) to $0(V)$. The equilibrium solution is, as is known, the Maxwell-Boltzmann distribution.[2] If friction is taken to higher terms, say $0(V^n)$ (n odd), we can find in this model the equation that must replace the Fokker-Planck. In order that the equilibrium distribution have the Maxwell-Boltzmann form, the Moyal expansion must be broken off after the $(n+1)$st term, and each retained derivate moment a_k taken to $0(V^{n+1-k})$.

* This work supported by the U. S. Air Force through the Air Force Office of Scientific Research, Air Research and Development Command.
[1] J. E. Moyal, J. Roy. Statist. Soc., Ser. **B11**, 150 (1949), 8.1; J. Kellson and J. E. Storer, Quart. Appl. Math. **10**, 243 (1952).
[2] G. E. Uhlenbeck and L. S. Ornstein, Phys. Rev. **36**, 823 (1930).

SATURDAY MORNING AT 9:15

Willard, South Ballroom

(M. L. POOL presiding)

Radioactive Nuclei, I

U1. Effect of Compression on the Decay Rate of Tc^{99m} Metal. R. A. PORTER AND W. G. MCMILLAN, *University of California, Los Angeles.*—Motivated by Bainbridge's[1] measurement, we have attempted a theoretical calculation of the change in lifetime of the internal conversion of Tc^{99m} in compressed Tc metal. We have employed the Thomas-Fermi statistical potential, corrected for the self-potential of the electron in question, to obtain the initial and final state electronic wave functions for two volumes: the normal uncompressed state and ten percent compression. Because the energy available is so low (~2 kev), the only contributions to the internal conversion coefficient come from the M and higher shells, and mainly from the $3p$ and $3d$ levels. The principal contribution to the *change* in the internal conversion coefficient comes, however, from the valence electrons, particularly the $4p$, $4d$, and $5s$ levels. In order to relate compression to pressure, we have estimated the compressibility of technetium metal to be 0.27 megabar^{-1}. From this compressibility and the assumption that the internal conversion coefficient is linear in pressure, we calculate for the experimental pressure of 0.1 megabar a fractional decrease in lifetime of $(2 \text{ to } 4)\times10^{-4}$, the variation residing in the uncertainty of the structure of the $4p$ band. This result agrees with Bainbridge's measurement (2.3×10^{-4}) within the accuracy of our calculation.

[1] K. T. Bainbridge (private communication).

U2. Accurate Method for Measuring Internal Conversion Coefficients.* D. C. LU, *Iowa State College* (introduced by C. L. Hammer).—The influence on internal conversion due to the finite size of the nucleus and its internal structure has been the topic of many recent theoretical investigations.[1-3] Experimentally, the techniques presently used for measuring ICC (internal conversion coefficient) involve tedius corrections. Results so obtained, with few exceptions, are associated with errors over $\pm10\%$ and are inadequate to serve as experimental checks on the recently published tables of ICC,[1,3] or to provide new information on nuclear structure through its influence on ICC as suggested by Church and Weneser.[3] For some γ rays, better accuracy can be obtained in ICC measurements by using the summing method employed by the author[4] some years ago. This method has been refined to yield results of $\pm1\%$ accuracy readily. For example, the ICC of the 150-kev E_3 transition of Cd^{111m} was measured to be 2.32 ± 0.025 as com-

pared with $\alpha_k+\alpha_L+\frac{1}{2}\alpha_M$ (unscreened) = 2.35 from the new tables. Applications to complicated decay schemes will be discussed, using Ba^{131} and Nd^{147} to illustrate the auxiliary techniques.

* Research Supported by U. S. Atomic Energy Commission.
[1] I. A. Sliv and I. M. Band, "Coefficients of internal conversion of gamma radiation" issued in the U. S. as Rept. 57 ICCKI. Physics Department University of Illinois.
[2] M. E. Rose in *International Conference on Nuclear Structure, Rehovoth, Israel* (North-Holland Publishing Company, Amsterdam, and Interscience Publishers, Inc., New York, 1958).
[3] E. L. Church and J. Weneser, Phys. Rev. **104**, 1382 (1956).
[4] Lu, Kelly, and Wiedenbeck, Phys. Rev. **97**, 139 (1955).

U3. Beta-Decay Energy of Tritium.* FRED T. PORTER, *Argonne National Laboratory.*—The extrapolated end point from Curie plots of the tritium beta spectrum between 14 and 18 kev has been measured as 18.61±0.02 kev on the Argonne double lens beta spectrometer. Composite sources of tritiated estradiol and 10-hr thorium *B* (Pb^{212}) and its daughters allow calibration at 25 kev (the "*A*" line) as well as some check on the effect of the source thickness on the *A* line. A review of other measurements shows agreement at a value of 18.6±0.1 kev among mass difference data, average energy determination, proportional counter work, and the present magnetic spectrometer result. Two notable exceptions give lower values, 18.2 and 18.0 kev—one an average energy determination, the other a magnetic spectrometer result. The 18.6-kev decay energy and a half-life of 12.43 years gives $ft = 1137 \pm 20$ sec.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.

U4. Comparison of the Values of the Radioactive Decay Constant of Be^7 in Be and BeS.* KENNETH T. BAINBRIDGE, *Harvard University,* AND ELIZABETH BAKER, *Brookhaven National Laboratory.*—The radioactive constant λ of Be^7 was compared in beryllium metal and in beryllium sulfide. The difference $\lambda(BeS) = 5.2_8 \pm 0.6 \times 10^{-4}$ λ(Be) is approximately four times greater than the value of Δλ obtained in the comparison of the metal and the oxide reported previously.[1] The result supports the idea that the bonding of BeS is more covalent in character than the ionic bonding of BeO.

* Supported jointly by the U. S. Office of Naval Research with Harvard University and by the U. S. Atomic Energy Commission.
[1] E. Segrè and C. E. Wiegand, Phys. Rev. **81**, 284 (1951); *ibid.* **75**, 39 (1949); Kraushaar, Wilson, and Bainbridge, Phys. Rev. **90**, 610 (1953).

U5. Half-Life Determination of N^{12}.* B. J. FARMER AND C. M. CLASS, *The Rice Institute.*—The half-life of N^{12} is one of the least well known half-lives among the high-energy beta emitters in the light nuclei. The only published value[1] is 12.5±1 msec. This half-life has now been redetermined, taking advantage of the relative ease with which N^{12} can be made by means of the $B^{10}(He^3,n)$ reaction. The He^3 beam was electrostatically deflected off the B^{10} target five times a second and the decay was observed during an 80-msec counting interval. The betas were detected with a 5-in.-long by 3-in.-diam plastic scintillator and the output, after being converted to pulses of constant amplitudes, was fed into a 256-channel analyzer. The base line of the analyzer was swept at a constant rate such that each channel corresponded to about 0.3 msec. The time scale was calibrated with a standard frequency crystal controlled oscillator. For comparison, the half-life of B^{12} was measured by the same method. A least squares fit to the data yielded a half-life for N^{12} of 11.2±0.4 msec, and for B^{12} a half-life of 20.4±0.4 msec. The latter value agrees well with the most recent determinations.

* Supported in part by the U. S. Atomic Energy Commission.
[1] F. Ajzenberg-Selove and T. Lauritsen, "Energy levels of light nuclei, VI" (submitted for publication to Nuclear Phys.).

U6. Electric Monopole Internal Conversion in Ca^{40} and O^{16}.* M. NESSIN, K. E. EKLUND, AND T. H. KRUSE, *Columbia University.*—EO internal conversion electrons from the decay of the O^+, 3.35-Mev state of Ca^{40} have been observed in an Alburger-type intermediate image pair spectrometer. The spectrometer was used to detect only the negatrons of the continuous pair distribution by substitution of a single small plastic scintillator for the split plastic scintillator pair detector and by placing a positron selection baffle on both sides of the iris. The continuous and line spectra, corrected for background and resolution, give a preliminary value $\Gamma_e/\Gamma_\pi = (0.64 \pm 0.06)\%$. The state was excited by bombardment of a thin Ca target with 5.08-Mev protons from the Columbia Van de Graaff generator. A similar search was made for EO internal conversion electrons from the 6.06 Mev O^+ first excited state of O^{16}, using the $F^{19}(p,\alpha)O^{16*}$ reaction and 1.88-Mev protons. No conversion peak was observed. A preliminary upper limit for the ratio Γ_e/Γ_π is 2.3×10^{-4}. Predicted values for the ratios from the expressions of Thomas[1] are 0.46% and 3.2×10^{-5} for Ca^{40} and O^{16}, respectively.

* This work was partially supported by the U. S. Atomic Energy Commission.
[1] R. Thomas, Phys. Rev. **58**, 714 (1940).

U7. Internal Bremsstrahlung Spectrum Accompanying *s*-Electron Capture in Decay of Fe^{55} and Cs^{131}.* M. H. BIAVATI, S. NASSIFF, AND C. S. WU, *Columbia University.*—The internal bremsstrahlung spectra in coincidence with the *K* x-rays resulting from *s*-electron captures in Fe^{55} and Cs^{131} have been measured. The shape of the coincidence spectra exhibits a maximum at the predicted energy and then drops off in intensity toward the low-energy region. This is markedly different from that of single bremsstrahlung spectrum which rises continuously toward the low-energy region. The agreement between the observed coincidence shape and that predicted by Glauber and Martin[1] of the radiative capture of *s* electrons is excellent. In the case of Cs^{131}, the shape of the bremsstrahlung of the radiative capture of *p* electrons as obtained by subtracting from the total spectrum the spectrum due to *s*-electron capture is also in good accord with that predicted. The experimental setup involves thin NaI crystals enclosed in thin Be or Al windowed containers and a fast-slow coincidence circuit of resolving time varying from 10^{-8} to 10^{-7} sec. The amount of coincident x-rays in the bremsstrahlung detector was estimated by supplementary measurements and was subtracted for the final results.

* This work was partially supported by the U. S. Atomic Energy Commission.
[1] R. J. Glauber and P. C. Martin, Phys. Rev. **104**, 158 (1956).

U8. Decay of Fe^{59} (45 Days).* R. L. HEATH, D. G. PROCTOR, AND C. W. REICH, *Phillips Petroleum Company, Idaho Falls.*—The beta and gamma radiation emitted in the decay of Fe^{59} have been studied with single crystal and coincidence scintillation spectrometers. The following gamma rays were observed to decay with a 45-day half-life: 0.145±0.005, 0.192±0.005, 0.335±0.01, 1.10±0.01, and 1.29±0.01 Mev. The relative intensities of these gamma rays in percent of beta transitions were measured to be 0.8, 2.5, 0.3, 55.6, and 44.1, respectively. Gamma-gamma and beta-gamma coincidence measurements yielded results consistent with a decay scheme characterized by levels in Co^{59} at 1.10, 1.29, and 1.43 Mev. Gamma-gamma directional correlation measurements have been made on all cascades. A proposed level scheme will be discussed.

* This work performed under the auspices of the U. S. Atomic Energy Commission.

U9. Decays of Cu^{58} and Isomeric States in Co^{54} and Mn^{50}.* D. C. SUTTON, H. A. HILL AND R. SHERR, *Princeton University.*—The decay of 3.3-sec Cu^{58} has been shown to involve two positron branches to excited states of Ni^{58} in addition to the main (80%) ground-state transition of 7.4-Mev energy end point. A 6-Mev branch goes to the first excited state of Ni^{58}, 1.45 Mev. A 4.5-Mev branch goes to a level which decays by

two coincident, unresolved gamma rays of 1.45 Mev, and, partially, by crossover. Activities have been found of half-lives of 1.5 min in Co^{54}-Fe^{54} and 2 min in Mn^{50}-Cr^{50} which are independent of the $0^+ \rightarrow 0^+$ beta transitions. 1.5-min Co^{54} beta decays ($E_{max} \cong 4.3$ Mev) to a level at 2.97 Mev which decays by triple cascade. The gamma-ray energies fit the level scheme of Fe^{54} found by the MIT group.[1] In the decay of 2-min Mn^{50} several positron groups and six gamma rays have been found. The results of γ-γ and β-γ fast coincidence measurements will be given.

* This work was supported by the U. S. Atomic Energy Commission and The Higgins Scientific Trust Fund.

[1] Massachusetts Institute of Technology, Laboratory of Nuclear Science, 1956 Annual Rept., p. 112.

U10. Shape of the Beta Spectrum of Ga^{72}. L. M. LANGER, D. R. SMITH, AND D. C. CAMP, *Indiana University*.—The spectrum of the high-energy 3− to 2+ once forbidden beta transition of Ga^{72} is found to have a shape different from allowed. The data can be fitted with a shape factor which is dominated by the B_{ij} matrix element. This is consistent with the suppression of other matrix elements suggested by the high comparative lifetime ($\log ft \cong 9$). The end point is $E_0 = 3.15 \pm 0.01$ Mev. An excellent fit, yielding an end point for the next inner group consistent with the 0.63-Mev gamma transition, is given by $(W_0 - W)^2 + 0.95(W^2 - 1) + 15 \pm 10$. The measurements were made under conditions similar to those that yielded an energy independent shape factor over a comparable energy region for the 3.0-Mev transition[1] of Pr^{144}.

[1] J. H. Hamilton and L. M. Langer, Bull. Am. Phys. Soc. Ser. II, **3**, 208 (1958).

U11. Energies and Internal Conversion Coefficients of Transitions Following Se^{75} Decay. W. F. EDWARDS, C. J. GALLAGHER, JR., AND J. W. M. DUMOND, *California Institute of Technology*.—Disagreement between the conversion coefficients reported for the transitions in As^{75} following Se^{75} decay and the rest of the data on this decay scheme has been reported.[1] These conversion coefficients have been investigated using a bent crystal gamma spectrometer, a homogeneous field beta spectrometer, and a 180° beta spectrometer. The data from these instruments have been combined to give unnormalized conversion coefficients. Suitable normalization of the data appears to remove the reported disagreement. Transition energies measured with the bent crystal spectrometer are (in kev) 66.054, 96.741, 121.12, 135.99, 198.60, 264.62, 279.57, 304.0, and 400.7. The transition energies, level spin assignments, and conversion coefficients will be discussed.

[1] F. R. Metzger, Phys. Rev. **110**, 123 (1958).

U12. Decay of Rh^{106} and Ag^{106}. R. L. ROBINSON AND F. K. MCGOWAN, *Oak Ridge National Laboratory*, AND W. G. SMITH, *Purdue University*.—Single and coincidence gamma-ray spectra of 30-sec Rh^{106} ($I_0 = 1$) and 8.3-day Ag^{106} ($I_0 = 6$) have been investigated with scintillation spectrometers. Ag^{106} was produced by an (α,n) reaction on Rh^{103}. In addition to the well-known 0+ level at 1.137 Mev, the second 2+ level at 1.131 Mev which has been observed in Coulomb excitation[1] was found to be populated in the decay of Rh^{106}. The energies (and relative intensities) of gamma rays observed in the decay of Ag^{106} are 0.215(11), 0.41(26), 0.45(37), 0.513(100), 0.618(26), 0.725(49), 0.808(41), 0.85(12), 1.051(34), 1.128(11), 1.213(21), 1.54(26), and 1.77(3) Mev. From this decay energy levels have been proposed in Pd^{106} at 0.513(2+), 1.131(2+), 1.56(2), 1.94, 2.06, and 2.78 Mev. From the decay of Rh^{106} levels have been proposed in Pd^{106} at 0.513(2+), 1.131(2+), 1.137(0+), 1.56(2), 2.00, 2.28, 2.45, 2.61 Mev, and several other higher levels. For both Ag^{106} and Rh^{106} the branching ratio of cascade to crossover gamma rays from the second 2+ level is 2.3±0.3. This ratio combined with Coulomb excitation data[1] gives a value of 1.2±0.3 for the ratio $B(E2, 2' \rightarrow 2)/B(E2, 2 \rightarrow 0)$. Corrections for double $E2$ excitation and angular correlation effects are not included in this value.

[1] P. H. Stelson and F. K. McGowan, Bull. Am. Phys. Soc. Ser. II, **2**, 267 (1957).

U13. Decay of Ba^{139}. M. E. BUNKER AND J. W. STARNER, *Los Alamos Scientific Laboratory*.*—The radiations of Ba^{139} (85 min) have been studied with β- and γ-scintillation spectrometers. The γ rays observed have energies of 0.165, 1.26, and 1.425 Mev, and intensities (per disintegration) of 2.3×10^{-1}, 4×10^{-4}, and 3×10^{-3}, respectively. Coincidence studies indicate that the 1.425-Mev transition proceeds to the La^{139} ground state, and that the 1.26-Mev transition proceeds from the 1.425-Mev level to the well-known level at 0.165 Mev. The Ba^{139} β transitions have energies and log ft values of 2.38 Mev (6.9), 2.22 Mev (7.2), and 0.95 Mev (7.6). Possible state assignments for the observed levels will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

SATURDAY MORNING AT 9:00

Room B in Departmental Auditorium

(A. KLEIN presiding)

Theory, V: Quantum Theory; General

V1. Continuous One-Parameter Groups of Transformations in Classical and Quantum Mechanics.* GEORGE HINDS, *University of Maryland* (introduced by J. Weber).—The formalism of the theory of continuous groups of one-parameter transformations has been found to be a useful and elegant framework in which to imbed some of the ideas and techniques of classical and quantum mechanics—at least for those systems which may be conceived as arising from a one-parameter variational principle. The methods have their foundation in the two statements: $dS(s,0)/ds = S(s,0)I(s)$; $X(s) = S(s,0)X$; $I(s)$ is the infinitesimal generator, a differential operator, for the one-parameter group of transformations which characterizes the physical evolution of the system in s, more specifically realized in a statement of the values of the physical variables contingent on a given set of initial conditions. $S(s,0)$, the classical "propagator," is the operator one uses to obtain this information. To make the transition to the quantum mechanics of the corresponding classical systems, one need only insert two interpretive postulates; one concerning the different ways in which the (X) are to be regarded, and the second, a statement of two equivalent ways in which the variables propagate, enabling one to obtain a relation which in many cases can be solved, algebraically, to yield the desired commutation relations.

* Supported by the National Science Foundation.

V2. Quantum Mechanics of a Particle in a Multicentered Potential.* LEONARD J. EYGES, *Lincoln Laboratory.*—We consider the problem of a particle bound to a configuration of N *overlapping* potentials, each one of which is by itself spherically symmetric. We give reasons for preferring a multicenter representation of the wave function to a single center representation. For these reasons we try to represent the wave function ψ in the form $\psi=\psi_1(\mathbf{r}_1)+\cdots\psi_N(\mathbf{r}_N)$, where r_i refers to a coordinate system with origin at the ith potential. With $\phi_i(\lambda)$ defined as the Fourier transform of $\psi_i(\mathbf{r}_i)$, we derive a set of N-coupled integral equations for the functions ϕ_1, ϕ_N, and discuss applications of these equations. They can be used to develop a systematic perturbation theory whereby for small separations of the potentials one expands in terms of eigenfunctions of the coalesced potentials and for large separations one expands in terms of eigenfunctions of a single one of the potentials. For $N=2$ and Coulomb potentials, i.e., for the hydrogen molecule-ion we compare these results with known exact ones. We then discuss the practicality of the integral equations for $N>2$. It appears that they are particularly useful for symmetric states of symmetric configurations (equilateral, triangle, square, pentagon, etc.) where all the functions ψ_i are identical and the set of integral equations reduces to a single one.

* The work reported here was performed at Lincoln Laboratory, a technical center operated by Massachusetts Institute of Technology, with the joint support of the U. S. Army, Navy, and Air Force.

V3. New Theory of Quantum Fields. GEORGE J. YEVICK, *Stevens Institute of Technology,* AND JEROME K. PERCUS, *N. Y. U. Institute of Mathematical Sciences.*—A great problem in elementary particle theory is the necessity for new modes of approximation and calculation because of the strength and nonlinearity of interaction. We should like to propose a new method which appears to have the significant advantage of immediate physical interpretation. The basic idea is to describe elementary particle fields with the aid of *positive probability densities* on the full space of field amplitudes and conjugate momenta. There can be no negative probabilities in the theory. The scalar meson with a fixed source illustrates the techniques and concepts involved. There is an automatic smearing out of the effective source function. Our procedure promises to be useful in attacking the difficult problem of introducing in a natural manner a relativistic cutoff. The whole question of the physical meaning of "virtual" processes becomes amenable to analyses.

V4. Spin and Statistics in Positive Density Approach to Quantum Mechanics. JEROME K. PERCUS, *N. Y. U. Institute of Mathematical Science,* AND GEORGE J. YEVICK, *Stevens Institute of Technology.*—A large class of positive definite probability distributions in phase space has been obtained which can serve as starting point for a more rational quantum-mechanical perturbation theory for the many-body problem. There are two specifically quantum-mechanical features which arise in any attempted classical description, i.e., spin and statistics. If one tries to treat spin directly as a discrete quantity using the previously outlined positive δ-function approach, serious difficulty is encountered. On the other hand, the use of Kramers' continuous coordinates for spin allow an elegant classical description of quantum mechanical spin space. The Pauli particle serves as an illustrative example. Now the problem of statistics does not arise in a perturbation method as long as the unperturbed system is correctly formulated. Nevertheless, it is crucial for an understanding of the meaning of quantum statistics to have available a criterion for distinguishing the Einstein-Bose or Fermi-Dirac character of a given probability density. In the simple case of a harmonic oscillator weighting function, the criterion is readily ascertained. The appropriate criteria for other types of weighting functions are under investigation.

V5. High-Energy Behavior in Quantum Field Theory.* STEVEN WEINBERG, *Columbia University.*—We have proved a theorem in the mathematical theory of real variables that may prove quite useful in analyzing the behavior at high energy of the Green's functions of quantum field theory. We define a class A_n of functions of n real variables whose asymptotic behavior may be specified in a certain manner by a set of "asymptotic coefficients." (The integrands of perturbation theory have this property.) Judicious use of the Heine-Borel theorem allows us then to show that the integral of any function in A_n over $k<n$ of its arguments belongs to the class A_{n-k}, with new asymptotic coefficients that are given as functions of the old ones. Application of this theorem to perturbation theory gives a simple rule for the asymptotic behavior of any Green's function; this rule is just what is needed to justify the renormalization procedure of Dyson and Salam. Applications to a nonperturbative approach will be discussed.

* This work supported in part by the U. S. Atomic Energy Commission.

V6. Proof of Haag's Theorem. O. W. GREENBERG, *Air Force Cambridge Research Center.*—Haag's theorem[1,2] states—essentially—that a given relativistic field which, at a fixed time, is related by a unitary transformation to the free field, is completely equivalent to the free field throughout all space-time. Previously it had been proved that the vacuum expectation values of the given field equal the free field ones up to and including the fourfold vacuum expectation value. The present proof proceeds by induction, proving in each cycle of the argument that two more vacuum expectation values of the given field equal those of the free field. Strong use is made of the properties of the free field theory, and of the fact that the vacuum expectation values of both theories are analytic at certain sets of real vectors.[2,3] Among the implications of Haag's theorem is the fact that for relativistic theories the operator $U(0,-\infty)$, which is often introduced in discussions of field theory based on the interaction representation, cannot be unitary.

[1] R. Haag, Dan. Mat.-Fys. Medd. **29**, No. 12 (1955).
[2] D. W. Hall and A. S. Wightman, Dan. Mat.-Fys. Medd. **31**, No. 5 (1957).
[3] R. Jost, Helv. Phys. Acta **30**, 409 (1957).

V7. Generalized Gauge Transformations in Quantum Electrodynamics.* BRUNO ZUMINO, *New York University.*—Different forms of the photon propagator have been used in quantum electrodynamics in addition to the customary Feynman propagator. Landau and collaborators have used a transverse propagator, which is particularly suited to the study of ultraviolet divergences. More recently, Fried and Yennie have used a propagator which permits to eliminate the infrared divergence of the spurious charge renormalization. It is customarily assumed that these different forms are related through an "operator" gauge transformation, but the existing treatment of such gauge transformations does not seem quite satisfactory. It will be shown that it is indeed possible to define correctly a generalized gauge transformation connecting the various forms of the propagators. The usefulness of even more general gauge transformations will be discussed. The study of these gauge transformations is particularly simple and elegant in the formulation of quantum electrodynamics which makes use of functional differential equations. The generating functional of all propagators has very simple transformation properties. The relevance of the above results to renormalization theory will be discussed.

* Work supported by the Office of Naval Research.

V8. Free Propagator Expansion in the Evaluation of the Lamb Shift.* ARTHUR J. LAYZER, *Columbia University.*—Recently, Fried and Yennie have established the usefulness of the free-propagator expansion of the electron propagator

(expansion in powers of the Coulomb potential) for the Lamb shift problem. These authors employ a gauge transformation to generate a null counter series which removes the lowest order contributions from each term of the expansion. We have investigated order and analyticity [in $w=(\alpha Z)^2$] properties of the terms of the free propagator expansion of the Lamb shift matrix element without this counter series. A straightforward analysis yielded the formal but nonrigorous result that the lowest order nonanalytic in w contribution to the n-potential term is of order $\alpha w^{(n+2)/2}\ln w$ if n is odd or $\alpha w^{(n+2)/2}$ if n is even, for $n>3$; for $n=3$, it is $w^3\ln^2 w$. This indicates that the expansion is particularly suitable for nonanalytic in w contributions to the Lamb shift, such as the well-known $\alpha(\alpha Z)^4\ln\alpha Z$, the previously calculated $(\alpha(\alpha Z)^5$, or the as yet uncalculated $\alpha(\alpha Z)^6\ln^2(\alpha Z)$ contributions. We have, indeed, been able to rederive the $\alpha(\alpha Z)^4\ln\alpha Z$ and the $\alpha(\alpha Z)^5$ contribution by calculating the contributions from $n=0$, 1, and 2.

* Supported in part by the U. S. Atomic Energy Commission.

V9. Simplified Calculation of Vacuum Polarization Effects in Coulomb Scattering. PHILIP SCHWED AND W. RARITA, *RIAS.*—Previous calculations[1] have indicated that vacuum polarization effects alter the low angular momentum phase shifts for α-particle heavy nucleus Coulomb scattering to the same degree as in the case of p-p scattering. A simplified determination of the change of the cross section in the former case can be based on the approximation of the vacuum polarization potential ΔV by an expression quadratic in $1/r$ which is valid in the appropriate range. This approximation permits a simplified calculation of the phase shifts with results in agreement with the previous exact calculation.[1] Further, from the same expression, it is possible to estimate conveniently the change in the classical (Rutherford) cross section due to vacuum polarization. In each instance, the effect of the vacuum polarization is just to induce a change in the parameters (charge, mass, and angular momentum) entering the relevant expression. At large angles the change in the cross section for 4-Mev α particles on Au is about 0.3% by the classical calculation, a result presumably close to the quantum mechanical one[2] for the large η considered here.

[1] P. Schwed and W. Rarita, Bull. Am. Phys. Soc. Ser. II, **2**, 229 (1957).
[2] N. F. Mott and H. S. W. Massey, *The Theory of Atomic Collisions* (Oxford University Press, London, 1949), Chap. IV.

V10. Wave Operators in Multichannel Scattering.* M. N. HACK, *Argonne National Laboratory.*—The convergence to the wave operators and the completeness property of the scattering states have been adopted as the fundamental requirements for a multichannel scattering system.[1] The convergence property can be expressed as a condition on the scattering states: A normalizable state is an outgoing- or ingoing-wave scattering state of the channel α of a multichannel scattering system if, and only if, in this state the interaction in the channel α vanishes asymptotically, in an appropriately specified sense, in the distant past or future. The completeness property and the orthogonality and intertwining relations lead to an expression for the continuum part of the total Hamiltonian (the restriction to the subspace of scattering states) in terms of the wave operators and the channel Hamiltonians, $H_c=\Sigma_\alpha\,\Omega_\pm^{(\alpha)}H_\alpha\Omega_\pm^{(\alpha)*}$, where the (direct) sum is over all channels of the system. The convergence property is verified for typical multichannel scattering systems.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. M. Jauch, Helv. Phys. Acta **31**, 661 (1958).

V11. Nonadiabatic Treatment of Elastic Scattering of Electrons by Atomic Hydrogen. KAZEM OMIDVAR, *New York University.*—The elastic scattering of electrons by atomic hydrogen including the effects of exchange and polarization is calculated. To include the exchange effect the total spin and space function of the incident and the bound electrons is made antisymmetric with respect to interchange of the two electrons. To include polarization, the wave function for the bound electron is taken in such a way that the electrostatic potential energy between the incident electron and the atom with this wave function becomes equal to the average classical Coulomb and dipole potential energy of the incident electron. Since the exchange potential depends on the form of the bound electron wave function, the effect of polarization on the exchange scattering is also taken into account. The equation for the wave function of the incident electron is reduced to a set of radial integro-differential equations. These equations are integrated numerically up to d wave using for the bound electron wave function: first, the ground state of hydrogen atom wave function, and second, the wave function calculated according to the above scheme. In the second case the calculated curve reproduces most features of the experimental curve of Bederson *et al.*

V12. Shifts in Hyperfine Frequencies of Alkalis Caused by Foreign Gases.* PETER FONTANA, *Yale University* (introduced by H. Margenau).—The difference in the dispersion force between an alkali atom in a particular hyperfine level belonging to the ground state and a perturbing molecule is computed in terms of radial matrix elements and Clebsch-Gordan coefficients. A second-order perturbation calculation when applied to each hyperfine level separately shows that the energy difference depends mainly on the separation of the two levels and becomes zero when the hyperfine splitting is neglected. These asymptotic forces, if active alone, produce red shifts and suffice to account for the results obtained for the heavier buffer gases. Experimental data[1] exhibit blue shifts for the lighter gases and therefore suggest the action of exchange as well as dispersion forces. The use of a theory given by Margenau[2] leads to results which are in agreement with experimental data when simple provision for "repulsive" interactions at small distances is made.

* Research supported by the Office of Naval Research.
[1] Bender, Beaty, and Chi, Phys. Rev. Letters **1**, 311 (1958); M. Arditi and T. R. Carver, Phys. Rev. **112**, 449 (1958); M. Arditi, J. phys. radium **19**, 873 (1958).
[2] H. Margenau, Phys. Rev. **40**, 387 (1932).

V13. Correction to the Deuteron Magnetic Moment. H. D. YOUNG AND R. E. CUTKOSKY, *Carnegie Institute of Technology.*—Elementary calculations of the deuteron magnetic moment have assumed that the nucleon moments are not altered by the binding. A correction resulting from the altered expectation values of nucleon core spins in the bound state is calculated. The adiabatic approximation, in which the pion clouds are assumed to follow the orbital motion of the sources, is used. The two-nucleon states are expanded in Heitler-London states; the matrix elements of the two-nucleon magnetic moment operator are related to single nucleon matrix elements,[1] which are evaluated using the Chew-Low-Wick fixed source theory. If a deuteron orbital wave function is used which contains a relatively large d-state probability and corresponds to a potential containing a repulsive core, an increase of the deuteron moment of about 1% is obtained from the contributions corresponding to exchange of one meson between the nucleons. This correction is quite sensitive to the shape of the deuteron wave function at small distances. The two-meson exchange contributions appear to be smaller than the one-meson terms.

[1] R. E. Cutkosky, Phys. Rev. **112**, 1027 (1959).

V14. Contribution of Spin-Orbit Forces to the Deuteron Photoeffect.* ALBERT ARKING, *Cornell University.*—Calculation of the interaction (pion exchange) contribution to photomagnetic transitions of the two-nucleon system with the present form of meson theory is uncertain. It is therefore of interest to investigate the influence of the spin-orbit interac-

tion, which itself is not derived from meson theory but known to exist from phenomenological considerations. The spin-orbit potentials proposed by Signell and Marshak, Gammel and Thaler, and Newton and Fulton all give corrections to the thermal n-p capture cross section about two orders of magnitude too small to cover the 7% discrepancy between the experimental value of the cross section and the theoretical value neglecting interaction effects. Modification of the spin-orbit potential to give as much as a 4% effect would require either increasing the range by a factor of three, or increasing the depth by a factor of thirty, or increasing both by lesser factors. Such a modification, however, would have an enormous effect on the magnetic moment of the deuteron—enough to change its sign if the spin-orbit force is attractive.

* Supported in part by the joint contract of the Office of Naval Research and the U. S. Atomic Energy Commission.

SATURDAY MORNING AT 9:30

Commerce Auditorium

(W. M. ELSASSER presiding)

Invited Papers of the Division of Fluid Dynamics

VA1. Propagation of Hydromagnetic Disturbances in a Perfectly Conducting Fluid. HAROLD GRAD, *New York University.* (45 min.)

VA2. Optical Properties of Dissociated and Ionized Gases. R. A. ALPHER, *General Electric Research Laboratory.* (30 min.)

VA3. A Statistical Theory of Turbulent Convection. W. V. R. MALKUS, *Woods Hole Oceanographic Institution.* (30 min.)

VA4. An Experimental Investigation of Boundary Layer Instability. P. S. KLEBANOFF, *National Bureau of Standards.* (30 min.)

SATURDAY AFTERNOON AT 1:30

Commerce Auditorium

(R. J. EMRICH presiding)

Invited Paper

W1. The Statistical Mechanics of Rigid Spheres. HOWARD REISS, *Bell Telephone Laboratories.* (30 min.)

Fluid Dynamics

W2. Mercury Table—A Magnetohydrodynamic Analogy.* R. A. ALPHER, R. H. JOHNSON, AND A. J. NERAD, *General Electric Research Laboratory.*—Free-surface water flow in a shallow rectangular channel provides a useful analogy to two-dimensional flows of an inviscid, compressible fluid whose specific heat ratio is two. The analogy relates gravity wave and sound velocity, depth changes with isentropic flow parameters, and the hydraulic jump with shock waves.[1] With the hope of an equally useful analogy for magnetohydrodynamics, a table had been constructed in which mercury flows in a channel through a transverse magnetic field. Conducting walls, combined with an insulating bottom, with circuit closure external to the mercury, allow currents induced by the magnetohydrodynamic interaction to flow in such a way as to generate body forces in the mercury opposing those due to gravity. The pressure gradient is $10^{-5}\ VH^2$ dynes/cm^2/cm, with V in cm/sec, H in gauss. Gradients more than adequate for experiments are generated by a steady dc magnet, having 60-cm-diam pole pieces, which provides up to 5000 gauss in a 10-cm gap. A variety of experiments will be described which not only demonstrate magnetohydrodynamic effects but also help in understanding the nature of the analogy which the device provides. Some of the theoretical problems associated with the analogy will be discussed briefly.

* This work was supported in part by the Ballistic Missile Division, U. S. Air Force.

[1] See, for example, E. Preiswerk, NACA TM 934,935 (March, 1940).

W3. On Some Mathematical Aspects of Quantum Hydrodynamics. M. Z. v. KRZYWOBLOCKI, *University of Illinois.*—The author discusses some mathematical aspects of the quantum hydrodynamics as referred to possible subfields of this field like continuum, discrete particle approach, etc. From these the problem of the "passage" from the microscopic to the macroscopic domain seems to be the most challenging.

W4. On Unsteady Incompressible Flow of Electrically Conducting Fluids through Two-Dimensional Channels. C. C. CHANG AND J. T. YEN, *University of Minnesota.*—Unsteady incompressible flow of electrically conducting fluid through two-dimensional channels with perfectly conducting or nonconducting walls will be investigated herein when a transverse magnetic field is applied. The unsteadiness of the flow is effected first by an impulsive, arbitrary motion of one of the channel walls and second by an applied, variable pressure gradient. For both cases, the flow problem is solved when channels consist of perfectly conducting walls; also, it is found to admit a much simpler solution technique in comparison with other findings.[1] The impalpability of arriving at a solution for general fluid appears, however, if the channels become perfectly nonconducting. Only for a particular kind of fluid the solution is arrived at and compared with various solutions for perfectly conducting walls. The effects of un-

steadiness on over-all behaviors of the flow problem will also be attended to.

[1] C. C. Chang and J. T. Yen, "On Rayleigh's problem in magnetohydrodynamics," Phys. Fluids (to be published).

W5. Measurement of Shock Wave Thickness in Argon.* RUSSELL E. DUFF AND WALTER M. WEBSTER, *Los Alamos Scientific Laboratory*.—A modified version of the electron-beam densitometer described by Venable[1] is being used to measure shock structure in argon. Preliminary results for maximum slope thickness will be presented. All measurements were made in a 1¾-in. i.d. shock tube. The diameter of the beam collimating apertures was 0.002 in. Measurements were made at shock Mach numbers between 1.6 and 7.0 at $p_0=0.5$ mm Hg. Corrections to the measured values of thickness were computed assuming a sine squared shock density profile and finite beam diameter, finite electonic time response, measured shock wave curvature, and exponential dependence of electron transmission on density. The corrected results indicate a shock thickness about 25% larger than that found by Greene and Hornig,[2] a difference comparable with the experimental uncertainties in both measurements. The measured thickness decreased rapidly to a minimum at $M_s=3$ of 6.5 mean free paths computed at p_0 and increased slowly for stronger waves. At $M_s=3$ it was more than twice the theoretical thickness computed from the Navier-Stokes equations and a temperature exponent of viscosity of 0.816.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] H. N. Ballard and D. Venable, Phys. Fluids **1**, 225 (1958).
[2] E. F. Greene and D. F. Hornig, J. Chem. Phys. **21**, 617 (1953).

W6. Precursor Signals from Shock Waves in Xenon.* PER GLOERSEN, *General Electric Company*.—A number of external potential measurements have been made on helium-driven shocks in high purity xenon. The shock tube is constructed of glass, with a brass end plate, and is capable of being pumped out to pressures lower than 3×10^{-6} mm Hg. Three probes were recorded simultaneously on an oscilloscope: two external brass rings[1] spaced 40 cm apart and the brass end plate. Positive-going signals were observed due to the passage of the shock through each ring in succession. Negative-going signals were observed simultaneously at all three probes at earlier times, i.e., before the shock reached either of the external rings, and at distances up to 1.5 meters from the end plate. These precursor signals occurred at the same time that the delayed luminosity appeared at an upstream point. About 1 μa flowed between ground and the end plate for a period of 400 μsec, during the approach of the incident shock. Evidence will be given to support the contentions that the precursor signals are runaway electrons originating behind the shock and/or photoelectrons due to radiation from behind the shock.

* Based on work performed under the auspices of the U. S. Air Force Ballistic Missile Division.
[1] H. D. Weymann, "On the mechanism of thermal ionization behind strong shock waves," Tech. Note BN-144, Institute for Fluid Dynamics and Applied Mathematics, University of Maryland.

W7. Production of Very High Speed Shock Waves.* R. M. PATRICK, *Avco Research Laboratory* (introduced by A. Kantrowitz).—A magnetically driven coaxial shock tube has been used to produce shock waves with very high velocities.[1] In this device there is a magnetic field ahead of the shock front with its principal component in the plane of the shock front. The continuum radiation emitted by the shock-heated gas has been measured with photomultipliers. The use of probes to measure the change in the local magnetic field at the shock front has been investigated. Time integrated spectra have been taken of the light emitted from the shock tube. Shock velocities in excess of 3×10^7 cm/sec have been measured in hydrogen. For these high-speed shock waves, the shock thickness has been obtained from the measured rise times of the emitted visible radiation. These shock thicknesses are thinner than a mean free path for the conditions in the shock-heated gas, which agrees with a theoretical prediction.[2]

* This research was supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.
[1] R. M. Patrick, Bull. Am Phys. Soc. Ser. II, **3**, 39 (1958).
[2] H. E. Petschek, Revs. Modern Phys. **30**, 966 (1958).

W8. Use of Hydrodynamics in Treating Shock Waves in Solids. G. E. DUVALL AND J. S. KOEHLER, *Stanford Research Institute*.—The Rankine-Hugoniot equations have been used to describe the changes in pressure, volume, and velocity which occur when a shock wave passes through a solid. The three equations express the conservation of mass, momentum, and energy for specimen material as the shock passes over it. The variables involved are hydrodynamic variables appropriate for a liquid. A solid resists shearing stresses; therefore, one would expect a more complex description would be necessary. However, for plane shock waves in which the pressure is greater than about 5×10^{10} dyne/cm^2 it is found that the very large shearing stresses which occur in the shock front produce plastic deformation. The shearing stresses are large enough to generate dislocation pairs in the perfect crystal if dynamic effects do not predominate. Moreover, the energy density in the shock ($>10^{10}$ ergs/cm^3) is so large that the loss resulting from dislocation production and motion would not give rise to appreciable attenuation of the shock. Experiments available are in agreement with this description. The plastic deformation is observed in copper and aluminum. Moreover, Walsh, Rice, McQueen, and Yarger found that the velocity of a plane shock is independent of direction in zinc single crystals.

W9. Shock Wave Data and the Closed Shell Repulsive Potential in the Noble Metals. J. S. KOEHLER, *University of Illinois*.* AND G. E. DUVALL, *Stanford Research Institute*.—Walsh *et al.*[1] have calculated pressure *versus* volume curves appropriate for 0°K using their shock wave data. These data were treated using the Hugoniot equations to obtain a Hugoniot pressure *versus* volume point from the observed particle velocity and the measured shock wave velocity. The Hugoniot pressure volume point was then temperature corrected to 0°K. We have fitted the resulting 0°K curve to the following expression to obtain an estimate of the closed shell repulsive potential for copper and gold.

$$pv=-v\partial E/\partial v=A(v_0/v)+\tfrac{2}{3}B(v_0/v)^{\frac{1}{3}}-\tfrac{1}{2}C(v_0/v)^{\frac{1}{3}}+\tfrac{1}{2}H\alpha\exp\{\alpha[1-(v/v_0)^{\frac{1}{3}}]\},$$

where v is the volume per atom under pressure p. v_0 is the atomic volume at 0°K under no pressure, and E is the energy per atom. One finds that for copper $A=4.0000$, $B=5.8504$, $C=+17.8438$, $H=1.7440$ (all these multiplied by 10^{-12} ergs/atom). $\alpha=10.06$.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Walsh, Rice, McQueen, and Yarger, Phys. Rev. **108**, 196 (1957).

W10. Effect of Gas Pressure and Cone Angle on the Velocities of Electrically Excited Shock Waves. PHILIP J. HART, *Lockheed Missiles and Space Division*.—The behavior of electromagnetically excited shock waves depends in a complex manner on many factors. An experimental investigation of the effect on shock wave velocity of the two variables, original gas pressure in the shock tube, and cone angle of an axially symmetric electrode configuration, has been conducted with all other parameters held constant. The energy source is a 2.2-mf capacitor charged to 30 kv, used with a series triggered spark gap, and having a ringing frequency of 220 kc. The gas used is air, the plasma being discharged into a two-inch shock tube. Velocities are determined from streaking pictures from an image converter camera. The curve of shock velocity *vs* pressure for each cone angle is found to be very nearly a straight line on a logarithmic scale, but the slopes of the

curves vary markedly with cone angle. These curves, for the given conditions, cross each other at about 1 mm of Hg pressure in such a manner that at lower pressures the greater shock velocities are produced by the larger cone angles, while at higher pressures the smaller cone angles are more effective. Reasons are proposed for this behavior.

W11. On the Mechanism of Thermal Ionization.* H. D. WEYMANN, *University of Maryland.*—A theory is given for the thermal ionization behind strong shock waves. It is shown that the process which essentially determines the time to reach a definite degree of ionization consists of a two-step mechanism in which an atom is first excited to the resonance level by a collision with another atom and then becomes completely ionized in a successive collision with an atom, assuming in both cases that sufficient translational energy is available. The theoretical results concerning the dependence of the ionization rate on time and temperature are in good agreement with the experimental results. A comparison of the theoretical and the experimental results further allows a determination of the excitation cross sections for atom-atom collisions. The diffusion of electrons out of an initially neutral plasma is considered and expressions are given for the stationary electron density and the resulting potential. Experimentally measured diffusion potentials agree well with the calculations.

* This work was partly supported by the Air Force Office of Scientific Research.

SATURDAY AFTERNOON AT 1:30

Departmental Auditorium

(E. BURSTEIN presiding)

Invited Papers

WA1. Fine Structure in the Zeeman Effect of Excitons in Germanium. LAURA M. ROTH, *Lincoln Laboratory.* (30 min.)

WA2. Recent Studies on Magneto-Surface Properties of Germanium. J. N. ZEMEL, *U. S. Naval Ordnance Laboratory.* (30 min.)

Irradiation Effects

WA3. Transient Processes in the Optical Bleaching of Color Centers in Potassium Chloride.* L. I. GROSSWEINER AND A. R. REINBERG,† *Illinois Institute of Technology.*—Transients in the optical bleaching of color centers in potassium chloride crystals were studied by bleaching with 10-μsec light pulses while continuously monitoring the transmission in the F band. When crystals are x-rayed at room temperature, rapidly cooled, and bleached between 500 and 600 mμ, there is a fast (less than 1 μsec) decrease in the F-band density followed by an almost complete dark recovery after some 20 msec. The quantum yield for fast bleaching is 0.063 ± 0.010 from -165 to -100°C, and decreases above -100°C to limiting detectability at 25°C. When the bleaching light is above 600 mμ, with other conditions identical, there is a rapid increase in F-band density, again followed by a complete dark return. This process is not observed above -20°C. The durations of the recovery processes are insensitive to temperature. However, the extent of both bleaching processes varies with the history of the sample, and depends particularly upon the presence of M and R centers. The rapid bleaching processes are presumably due to the destruction of F and F' centers by green and red light, respectively. It is believed that the recovery, in both cases, is due to the temporary capture of the photoejected electrons at neutral vacancy pairs.

* Supported in part by the U. S. Atomic Energy Commission.
† Ohmite Fellow, 1957–1958.

WA4. X-Ray Coloration of Ruby.* JOHN H. MATHEWS AND JOHN LAMBE, *Willow Run Laboratories.*—Ruby exhibits an x-ray coloration well in excess of that of white sapphire[1,2] and anomalously dependent on chromium concentration. The induced optical density first increases and then decreases with chromium concentration. Absorption measurements on annealed, synthetic sapphires (Linde) with 0 to 4% Cr_2O_3 "nominal powder concentration" show a broad radiation-induced band, peaking at about 4700 A, and a second band near the absorption edge. Induced absorption coefficients reach 5 and 25 cm^{-1} at 4700 and 2300 A, respectively, at saturation. Similar effects are observed with Co^{60} gamma irradiation. The sensitizing effect of the chromium ion may be due to its providing, under irradiation, electrons for color centers. The anomalous down-turn of irradiation coloration at the higher chromium concentrations would appear to exclude as dominant sensitization mechanism a simple furnishing, by the chromium ions, of sites for potential color centers.

* Work supported by Project MICHIGAN and the Air Force Office of Scientific Research.
[1] R. A. Hunt and R. H. Schuler, Phys. Rev. **89**, 664 (1953).
[2] P. W. Levy and G. J. Dienes, *Report of the Conference on Defects in Crystalline Solids* (The Physical Society, London, 1955).

WA5. Calorimetric Studies on Annealing Quenched-In Defects in Gold. WARREN DESORBO, *General Electric Research Laboratory.*—Preliminary measurement[1] of the energy released on annealing quenched-in defects in gold have been extended with an improved calorimetric technique. The energy can be described by an equation, $\Delta E = B\exp(-E_F/kT_Q)$, where ΔE is the total energy evolved for a quench from temperature, T_Q. B is a constant equal to $(4.5\pm1.0)\times10^4$ cal/g-atom (quenching rate $\sim1\times10^4$ °C/sec). E_F, the energy of formation of the defect, is equal to 0.97 ± 0.1 ev in good agreement with the value obtained from resistometric studies.[2] Assuming that the quenched-in defects are single vacancies,[2] the energy measurements can be combined with the resistivity data of Bauerle and Koehler,[3] to give the resistivity increase per 1 atomic% vacancies, $\Delta\rho/\Delta E/E_F$, using only experimentally derived quantities. This ratio equals $1.8_6\pm0.5$ μohm cm/atom%. The volume increase per vacancy determined from the ratio, $\Delta\rho/\Delta E/E_F$, and the proportionality constant between resistivity and fractional volume change[2] is $0.5_6\pm0.1$ in good agreement with recent theoretical work of Tewordt.[4]

[1] W. DeSorbo, Phys. Rev. Letters **1**, 238 (1958).
[2] J. E. Bauerle and J. S. Koehler, Phys. Rev. **107**, 1493 (1957).
[3] Koehler, Seitz, and Bauerle, Phys. Rev. **107**, 1499 (1957).
[4] L. Tewordt, Phys. Rev. **109**, 61 (1958).

WA6. Irradiation-Induced Phase Transformations in Perovskite-Type Crystals. M. C. WITTELS, *Oak Ridge National Laboratory.**—A diverse group of perovskite-type crystals were exposed to fast neutrons at a temperature of ~85°C. Preliminary studies of crystals irradiated with dosages in excess of 10^{19} neutrons/cm² indicate that their lattice stability under neutron irradiation very markedly depends upon the original crystal symmetry. Those crystals which possess cubic or pseudo-cubic symmetry, for example $SrTiO_3$ and $CaTiO_3$, tend to remain stable under irradiation dosages that are sufficiently heavy to transform the noncubic crystals into structures possessing cubic symmetry. Examples of the latter are $BaTiO_3$, $KNbO_3$, and $PbTiO_3$, all of which deviate from the ideal perovskite structure at room temperature, but possess cubic phases at higher temperatures. In effect, the higher form of lattice symmetry appears to be most stable upon exposure to fast neutrons. The thermal stability of these transformed crystals following irradiation will be presented.

* Oak Ridge National Laboratory is operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

WA7. Short-Lived Centers in Irradiated Germanium-Doped Quartz. JOHN H. ANDERSON, *University of Pittsburgh*, AND W. KOTH, *Mellon Institute.*—Two new, short-lived centers have been found in x-irradiated germanium-doped quartz. The principal values of the g tensors are: for the Y center, $g=1.998$, $g=2.000$; for the Z center, $g=1.998$, $g=1.999$. The g axes are parallel to the three-fold axis of the crystal. The lines are about 0.5 oe wide. No hyperfine structure has been resolved. Crystals from two separate batches of germanium-doped quartz show these centers. A crystal free from germanium impurity, when treated in the same manner, developed neither the Y and Z centers nor the previously reported A and C centers.[1] It did, however, develop the smoky color characteristic of the aluminum center.[2] If a sample of germanium-doped quartz is x-irradiated for 20 sec at room temperature and examined within 5 min after irradiation, the Y and Z lines appear about 10 times as intense as the A and C lines. The intensity of the Y and Z lines decays nonexponentially with time. After 24 hr at room temperature these lines are barely detectable. In the same time the intensity of the A and C lines remains unchanged.

[1] J. H. Anderson and J. A. Weil, Bull. Am. Phys. Soc. Ser. II, **3**, 135 (1958).
[2] M. C. M. O'Brien, Proc. Roy. Soc. (London) **A231**, 404 (1955).

WA8. Some Effects of Neutron Irradiation on MgO.* W. C. SCHIEVE, M. A. POMERANTZ, AND R. A. SHATAS, *Bartol Research Foundation.*—Electrical conductivity[1] and post-bombardment conductivity[2] induced in MgO crystals by electron irradiation have been investigated following exposure to neutrons in the Brookhaven pile (integrated fluxes 4.2×10^{16} n/cm² and 5.1×10^{17} n/cm², respectively). A change in carrier lifetime was observed. No change in the temperature dependence of the yield was detected, indicating that the mobility of the charge carriers is unaffected by these irradiations. The 1.4-ev shallow trap previously observed[2] was split into two levels by the neutron bombardment. This adds weight to the association of this level with the 2.1-ev level observed optically. Optical absorption measurements were conducted in the 0.6- to 3-ev range, and a previously unreported peak has been observed at 0.74 ev.

* Assisted by Office of Ordnance Research, U. S. Army.
[1] Marshall, Pomerantz, and Shatas, Phys. Rev. **106**, 432 (1957).
[2] Shatas, Marshall, and Pomerantz, Phys. Rev. **109**, 1953 (1958).

WA9. Electron Irradiation of Tellurium at 78°K. H. ROTH AND V. A. J. VAN LINT, *General Atomic.**—Specimens of high purity tellurium single crystals[1] have been irradiated at 78°K with 20-Mev electrons from the General Atomic electron linear accelerator. The conductivity of samples with current parallel to the c axis is observed to increase linearly with radiation up to 10^{14} electrons/cm². The rate of change of conductivity is 1×10^{-14} mho cm^{-1} per electron/cm². Beyond 10^{14} electrons/cm² the increase of conductivity is slower, but is not observed to saturate at the maximum irradiation of 10^{15} electron/cm². Since there is no initial decrease in conductivity observed in the p-type samples, the radiation is presumed to introduce additional acceptors. Annealing studies show that the radiation damage disappears after a few hours at room temperature. Experiments were performed on 20 ohm-cm n-type germanium at 78°K which indicate a comparable initial rate of change of conductivity with irradiation. Experiments in progress on tellurium samples with current perpendicular to the c axis indicate similar results.

* John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.
[1] Grown by the Czochralski technique by T. J. Davies and provided by G. D. Long, Honeywell Research Center, and described by H. Roth, J. Phys. Chem. Solids (to be published).

WA10. 90°K Electron Irradiation of Cold-Worked Copper.* A. SOSIN, C. J. MEECHAN, AND J. A. BRINKMAN, *Atomics International.*—Pure copper wires were reduced in area at 293°K by 18%, heated to 373°K for 30 min, and then irradiated at 90°K with 1.25-Mev electrons. Radiation-induced changes in the residual electrical resistivity were measured as a function of exposure. Following the irradiation, the resistivity recovery was observed upon heating the specimen in 10°K intervals up to 333°K. A second irradiation on the same specimen was then performed and an isothermal recovery curve was obtained at 273°K. These data differ significantly from those obtained previously[1] on initially annealed copper wires. The primary differences are (1) the damage rate for the cold-worked specimen is approximately twice that of the annealed specimen whereas there is little difference during a 12°K irradiation; (2) the exposure curve for the cold-worked specimen contains a quadratic term in addition to a linear term; (3) the present Stage III recovery kinetics are shifted from second order (annealed case) toward first order; (4) the center temperature of Stage III is shifted down in temperature 23°K below that of the annealed specimen; (5) the activation energy for Stage III is increased from 0.60 ev (annealed case) to 0.67 ev.

* Work supported by the U. S. Atomic Energy Commission.
[1] C. J. Meechan and J. A. Brinkman, Phys. Rev. **103**, 1193 (1956).

SATURDAY AFTERNOON AT 1:30

Willard, Congressional Room

(G. M. TEMMER presiding)

Nuclear Reactions, II

X1. Threshold Analysis of Li and LiF Targets.* C. D. BOWMAN, L. W. WESTON, E. G. BILPUCH, AND H. W. NEWSON, *Duke University.*—The energy distributions of neutrons from Li and LiF targets have been investigated near the forward threshold of the $Li^7(p,n)Be^7$ reaction. The effects of the solid angle of the McKibben counter and of the $Li^7(p,n)Be^7$ total

cross section[1] [as calculated from σ_{pn} is proportional to $\lambda_p^2\Gamma_n\Gamma_p/(\Gamma_n+\Gamma_p)^2$] are extracted from the experimental threshold measurement to obtain the energy distributions of the neutrons and of the protons which produce them. These distributions give information of the structure of Li metal and LiF targets, If yield is the prime consideration in selecting a target, the yield from Li metal targets appears to be considerably better than that for LiF targets for a given neutron energy spread. However, if minimum neutron energy spread is the prime consideration, LiF appears to be better than Li metal. Apparently thin LiF targets are more uniform in thickness than thin Li metal targets. Other applications and results of this technique will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Newson, Williamson, Jones, Gibbons, and Marshak, Phys. Rev. **108**, 1294 (1957).

X2. Nuclear Reaction Products from the Lithium Bombardment of Li^7 and Li^6 Targets.* G. C. MORRISON AND J. A. GALEY, *University of Chicago* (introduced by S. K. Allison).—A particle selection system is being used which allows a separation and identification of the protons, deuterons, tritons, and α particles emitted in lithium-induced nuclear reactions. The reaction products traverse a proportional counter and stop in a CsI (Tl) crystal giving a measure of the "dE/dx" and E of the particles, respectively. An oscilloscope displays the dE/dx and E pulses for each individual particle as X and Y deflections. A photomultiplier views the oscilloscope screen which is appropriately masked to discriminate against all particles other than those of interest. The gas pressure in the proportional counter is maintained at the smallest pressure compatible with good dE/dx resolution to minimize the energy loss before entering the CsI crystal. With methane at 4-cm pressure the total energy loss between the target and CsI (Tl) crystal is equivalent to that in 2.2 mg/cm² Al. Using this system the energy levels in B^{13} up to an excitation energy of 6 Mev have been investigated by means of the reaction $Li^7(Li^7,p)B^{13}$. Levels corresponding to the first four excited states have been observed at 3.83, 4.33, 5.25, and 5.74 Mev with an accuracy of ± 0.1 Mev which can be improved in subsequent runs. At 90° in the laboratory system the proton groups corresponding to the first and third excited states predominate.

* This research is supported in part by a grant from the U. S. Atomic Energy Commission.

X3. Yield and Angular Distributions from the Be(α,n) Reaction. R. V. SMITH, R. H. ABRAMSON, AND L. F. CHASE, JR., *Lockheed Missile and Space Division.*—A pulsed-beam time-of-flight technique has been used to obtain excitation functions for the neutron from the $Be^9(\alpha,n)C^{12}$ ($Q=5.708$ Mev) and the $Be^9(\alpha,n)C^{12*}$ ($Q=1.280$ Mev) reactions,[1,2] and for the 4.43-Mev de-excitation gamma rays from the latter reaction. The excitation functions were studied at zero degrees with respect to the incident beam, for alpha-particle energies from 1.7 to 3.1 Mev. Angular distributions of the separated neutron groups and gamma rays have been measured at 1.94, 2.36, and 2.70 Mev. The angular distributions change considerably in this energy interval, and suggest contributions from both compound nucleus formation and direct interaction processes.

[1] Bonner, Kraus, Marion, and Schiffer, Phys. Rev. **102**, 1348 (1956).
[2] Risser, Price, and Class, Phys. Rev. **105**, 1288 (1957).

X4. $Be^9(p,\alpha)Li^6$ Reactions at 15.6 and 18.6 Mev.* D. R. MAXSON, *Princeton University.*—A thin Be target was bombarded with protons and the alpha particles were detected with an ionization chamber. Alpha groups from $Be^9(p,\alpha)$ reactions to the ground state of Li^6 and to levels at 2.2 and 3.6 Mev were identified. A fourth group, clearly observed at small angles only, may correspond to a broad level near 5.6 Mev. Angular distributions of alphas from the reactions to the ground and 2.2-Mev levels were observed at $E_p=15.6$ and 18.6 Mev (lab), covering the angular range from 15 to 169 deg cm. The distributions are oscillatory, but there is no forward peaking. For the 2.2-Mev alpha group, the envelope of the entire distribution increases toward large angles, and the maxima are displaced toward larger angles at the higher proton energy, suggesting a heavy particle exchange mechanism. The average differential cross sections for the reactions to the ground and 2.2-Mev levels are 0.5 ± 0.1 and 1.8 ± 0.3 mb/sterad, respectively, at $E_p=15.6$ Mev, and 0.4 ± 0.1 and 1.2 ± 0.2 mb/sterad at 18.6 Mev.

* This work was supported by the U. S. Atomic Energy Commission and The Higgins Scientific Trust Fund.

X5. (α,d) Reactions on N^{14} and Li^6.* B. ZEIDMAN AND J. L. YNTEMA, *Argonne National Laboratory.*—Angular distributions of the emergent deuterons from the reactions $Li^6(\alpha,d)Be^8$ and $N^{14}(\alpha,d)O^{16}$, leading to the ground states of the final nuclei, have been obtained for an incident alpha particle energy of 43 Mev. The experiment was performed in the 60-in. scattering chamber, using a particle selection system employing a double NaI (Tl) crystal detector. The distributions cover the angular range between approximately 15° and 90° in the center-of-mass system exhibiting oscillatory behavior and forward peaking. Attempts to fit the data have been made. In the case of N^{14} a fairly satisfactory fit can be obtained if some heavy particle stripping is included. In the case of Li^6 it was not possible to obtain a satisfactory fit.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

X6. Na^{23} and $Al^{27}(\alpha,n)$ Reaction Energies.* T. S. KATMAN AND R. M. WILLIAMSON, *Duke University.*—Alpha particles from a Van de Graaff accelerator passed through a 90° electrostatic analyzer with a 1-m radius. The analyzer slits were set to give an energy resolution of 1/1000 and the analyzer was calibrated by observing the $Li^7(p,n)$ threshold at 1.8811 Mev. The first resonance in the $Na^{23}(\alpha,n)$ reaction was found at 3.491 ± 0.004 Mev ($\Gamma<1$ kev). At this resonance, the maximum angle at which neutrons were detected was $32°\pm3°$. From the above data the calculated $Q=-2.968\pm0.004$ Mev. The 6.5-sec positron activity of Al^{28m} was found at alpha energies greater than 3.83 Mev, in agreement with other observations of this decay.[1] Neutrons from the $Al^{27}(\alpha,n)$ reaction were first observed at an incident energy of 3.14 Mev. However, the positron activity of P^{30} appears first at 3.056 ± 0.005 Mev. From this data one can give only a limiting value of $Q\geqslant-2.662$ Mev for the $Al^{27}(\alpha,n)$ reaction. Background fast neutrons from the $C^{13}(\alpha,n)$ reaction obscured the off-resonance yields of neutrons in both of the foregoing reactions.

* Supported in part by the U. S. Atomic Energy Commission.
[1] P. M. Endt and C. M. Braams, Revs. Modern Phys. **29**, 683 (1957).

X7. (d,t) Reactions on Fe and Mn.* J. L. YNTEMA AND B. ZEIDMAN, *Argonne National Laboratory.*—The spectra from the (d,t) reaction at an incident of 21.6 Mev have been obtained for Mn^{55} and Fe. The tritons were identified by using a 0.012-in. NaI (Tl) crystal as the dE/dx counter and a 0.060-in. crystal as the E detector. The deuteron background was negligible. For Fe, $Q_0=4.95\pm0.10$ Mev. Triton groups were found at 0.43 ± 0.03, 1.28 ± 0.05, 1.88 ± 0.07, and 2.47 ± 0.07 Mev. For Mn^{55}, $Q_0=4.03\pm0.10$ Mev. Triton groups were found at 1.00 ± 0.05, 1.27 ± 0.05, 1.67 ± 0.05, 2.70 ± 0.05, 2.95 ± 0.05, 3.63 ± 0.07, and 3.85 ± 0.09 Mev. The intensity of the groups shows a pronounced angular dependence. Preliminary information on natural Ti and Zn targets has been obtained. Further measurements on the angular distribution

of the triton groups and on the triton spectra of separated isotopes in the region near $A=60$ are in progress.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

X8. $Ni^{60}(d,p)Ni^{61}$ Stripping Analysis.* R. A. FISHER† AND H. A. ENGE, *M.I.T.*—The MIT-ONR Van de Graaff generator and the broad-range spectrograph have been used to study the angular distribution of protons emitted from a Ni^{60} target bombarded with 7.5-Mev deuterons. Some preliminary results of the stripping analysis of the most intense proton groups are given in Table I. The excitation energies of other Ni^{61} levels have been given by Paris.[1]

TABLE I.

Ex (Mev):	0	0.061	0.276	1.176	2.121	2.695	3.491	3.734	4.902	5.506
l_n:	1	3	1	1	1	2	(2)	3	0	0

* This work is supported in part through AEC Contract AT(30-1)-2098 with funds provided by the U. S. Atomic Energy Commission, by the Office of Naval Research, and by the Air Force Office of Scientific Research.
† On leave from Northwestern University.
[1] C. H. Paris, MIT, Laboratory for Nuclear Science Progress Report, May 31, 1958, p. 120.

X9. (p,p') and (d,p) Reactions from Silver.* A. SPERDUTO, M. MAZARI,† AND W. W. BUECHNER, *M.I.T.*—Thin targets of natural silver and separated isotopes of silver 107 and 109 have been bombarded with protons and deuterons accelerated by the MIT-ONR Van de Graaff generator with energies up to 7.5 Mev. The emitted proton groups have been analyzed with the broad-range magnetic spectrograph with observations being made at several angles between 20 and 130 degrees. Proton groups from inelastic scattering have been identified with levels in Ag^{107} at 0.328, 0.425, 0.784, and 0.948 Mev and in Ag^{109} at 0.313, 0.416, 0.701, and 0.861 Mev. Evidences for a weak inelastic group, corresponding to an excitation energy of about 100 kev, have been observed from both isotopes. Increased exposures are being planned to obtain more precise measurements. The measurements of several proton groups from the (d,p) reactions have been made. The Q value of the ground-state transition for the $Ag^{107}(d,p)Ag^{108}$ reaction is 4.968 ± 0.010 Mev and that for the $Ag^{109}(d,p)Ag^{110}$ reaction is 4.585 ± 0.005 Mev.

* This work is supported in part by the U. S. Atomic Energy Commission, by the Office of Naval Research, and by the Air Force Office of Scientific Research.
† On leave from the National University of Mexico.

X10. p,n and p,γ Reactions from Recoil Protons in a Reactor.* STANLEY S. GLICKSTEIN AND ROLF G. WINTER, *The Pennsylvania State University.*—Samples of H_2BO_3, $(C_2H^4)_n$, and H_2O were exposed to the fast neutron flux next to the core of a 10^6-w "swimming pool" reactor. The reactions $B^{11}(p,n)C^{11}$, $C^{12}(p,\gamma)N^{13}$, $C^{13}(p,n)N^{13}$, and $O^{18}(p,n)F^{18}$ were initiated by recoil protons, and the positron activities of the products were observed. The yields, in atoms produced per gram of sample per second of irradiation, were 5000 for C^{11}, 800 for N^{13}, and 100 for F^{18}. These values are sufficiently high to permit usable sources to be made by this method. The fast neutron spectrum was measured with threshold detectors, and the yields were computed. The agreement of the calculated and measured results is good.

* Partly supported by the Office of Ordnance Research.

X11. (d,t) Reactions in Medium and Heavy Nuclei.* J. E. HAY, B. L. COHEN, AND R. E. PRICE, *University of Pittsburgh.*—(d,t) reactions induced by 15-Mev deuterons on various medium and heavy elements were studied by measuring energy distributions of the emitted tritons using magnetic analysis. Both scintillation and photographic plate detection were used, giving resolutions of approximately 250 kev and 70 kev, respectively. The spectra are peaked near the maximum triton energy as expected if hole states are being excited. The gross structure of the high-energy peaks generally consists of two or three peaks which exhibit striking regularities among neighboring nuclei; the fine structure of the peaks, however, varies widely for different nuclei. For even-even target nuclei there are strong peaks at or near the maximum energy although the product nucleus ground states are usually particle levels; this indicates that low lying particle and hole states are very close. Spins and parities of many of the peaks can be surmised from shell model, and positions of corresponding peaks can be followed from element to element. The gaps between major shells are generally evident. A perplexing similarity between the highly excited levels of Ti^{47} from $Ti^{48}(d,t)$ and $Ti^{46}(d,p)$ reactions was observed. Other elements are being studied for evidence of a similar situation.

* Supported by National Science Foundation and Office of Naval Research—U. S. Atomic Energy Commission joint program.

X12. Excitation of Vibrational Levels in Even-Even Nuclei by (d,p), (d,t), and (d,d') Reactions.* B. L. COHEN AND R. E. PRICE, *University of Pittsburgh.*—15-Mev deuteron-induced (d,p), (d,t), and (d,d') reactions in even-even nuclei in the vibrational region[1] were studied by measuring energy spectra of reaction products with 70 kev resolution. Some notable results were: (1) Cross sections for ground-state transitions relative to the most probable transitions in the spectrum are about 0.4 and 0.7 for (d,p) and (d,t) reactions, respectively; a much larger difference was expected since the former represents forbidden transitions [e.g., $(g_{7/2})^4S_{1/2}+n\rightarrow(g_{7/2})^6$] while the latter are allowed [e.g., $(g_{7/2})^4S_{1/2}-n\rightarrow(g_{7/2})^4$]. (2) Ratios of cross sections for first (and second) excited states to the ground-state cross section in (d,p) and (d,t) reactions are much larger than expected from weak coupling theory; in some nuclei these ratios are greater than unity. (3) No new levels in the region of the second excited states were found, and in all six cases where careful studies were possible, no levels were found for 350 kv–700 kv above the second excited state. (4) Cross sections for exciting first excited states in (d,d') reactions are closely proportional to Coulomb excitation cross sections; second excited states are excited 5–10 times less strongly.

* Supported by National Science Foundation, and ONR-AEC joint program.
[1] G. Scharff-Goldhaber and J. Weneser, Phys. Rev. **98**, 212 (1955).

X13. Mechanism of (p,t) Reactions at 22 Mev. J. B. BALL AND C. D. GOODMAN, *Oak Ridge National Laboratory.**—The energy spectra of tritons from 22-Mev proton-induced reactions of Zr^{90}, Zr^{91}, Zr^{92}, and Nb^{93} have been studied at a laboratory angle of 30 deg. Identification of the tritons is done with a proportional counter—NaI(Tl) scintillation-counter telescope using the multiplied $\Delta E\cdot E$ pulse to provide a gating signal. The tritons from Zr^{90} show essentially a single energy peak, from Zr^{91} show the same peak plus another at higher energy, and from Zr^{92} and Nb^{93} these two peaks with a third at still higher energy. The observed spectra seem to be consistent with the following interpretation: The (p,t) reaction proceeds primarily by a direct interaction between the incident proton and two neutrons in single particle shells leaving the remainder of the target nucleus undisturbed. The peak from Zr^{90} would then be assigned to pickup of two $g_{9/2}$ neutrons. The additional peaks from the other targets would be due to the pickup of a $g_{9/2}$ with a $g_{7/2}$ and two $g_{7/2}$ neutrons, respectively.

* Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.

X14. Further (n,p) Cross Sections near $Z=20$.* H. P. EUBANK, F. L. HASSLER, AND M. R. ZATZICK, *Brown University.*—Forward differential (n,p) cross sections have been

measured with a counter telescope for 14.1-Mev neutrons on the following elements, all of natural isotopic abundance: N, Cl, K, and Ca. Angular distributions (0–80°) have been made of N and Ca, the former having the gross structure of the C^{14} levels well resolved and exhibiting strong forward asymmetry. Comparison of the results about $Z=20$ which include, in addition to those listed above, A, Sc, Ti, V, Cr, and Ni with the work about $Z=50$[1] will be presented.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Eubank, Peck, and Al-Kital, Bull. Am. Phys. Soc. Ser. II, 3, 269 (1957).

X15. 14-Mev $(n,2n)$ Cross Sections.* L. A. RAYBURN, *Argonne National Laboratory.*—The $(n,2n)$ cross-section measurements reported previously[1] have been extended to include those nuclides listed in Table I. Absolute $(n,2n)$ cross sections are given, each having a standard deviation of about 8%.

TABLE I. Absolute $(n,2n)$ cross sections.

Target nuclide	Half-life of product nucleus	$(n,2n)$ cross section (millibarns)
Cl^{35}	31.7 min	5.3[a]
Ni^{58}	44 hr	33.4
Ge^{70}	39.6 hr	604
Br^{79}	6.3 min	788
Ru^{96}	1.6 hr	616
Sn^{112}	32.5 min	1400
Nd^{142}	2.53 hr	2480

[a] Lower limit since only one isomer was observed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] L. A. Rayburn, Bull. Am. Phys. Soc. Ser. II, 3, 337, 365 (1958).

X16. Nuclear Photon Scattering from Oxygen.* E. L. GARWIN AND A. S. PENFOLD, *University of Chicago.*—About 40 points on the 135° (γ,γ) cross section for oxygen have been obtained. A strong "giant resonance" occurs at 22 Mev where a cross section of 6.5 ± 1.3 μb/sterad was observed. The cross section decreases to 1 ± 0.3 μb/sterad by 45 Mev and remains at this value to at least 58 Mev. The angular distribution at the giant resonance is symmetric about 90° and predominantly dipole. The peak cross section at the giant resonance is 2.5 times larger than expected from published (γ,n) and (γ,p) cross sections combined with a dispersion theory. This behavior is explained by narrow isolated resonances in the oxygen photon absorption cross section near 22 Mev. Inelastic scattering to a state in oxygen near 6 Mev (probably the O^+ state) was also observed. The corresponding cross section has a threshold at about 27 Mev and a peak of 1.5 ± 0.3 μb/sterad (135°) at about 30 Mev. This behavior implies that the 6-Mev state has a "giant resonance" near 30 Mev instead of 22 Mev as for the ground state and is evidence in favor of the cooperative, or giant dipole, model of photonuclear reactions.[1]

* Research supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] J. Fujita, Progr. Theoret. Phys. 16, 112 (1956).

SATURDAY AFTERNOON AT 1:30

Willard, Grand Ballroom

(MURRAY GELL-MANN presiding)

Strange Particles

XA1. Possible Proton Polarization in K^+-Nucleon Scattering.* B. J. MALENKA, *Tufts University.*—The possible polarization of the recoil proton in K^+-p elastic scattering and in K^+-n charge-exchange scattering at high energies has been considered. Because of the relatively large K-meson mass, sufficient energy, e.g., 75% for center-of-mass scattering angles between 150° and 180°, is transferred to the recoil proton to permit the detection of the recoil proton polarization by the usual second scattering asymmetry measurements. This range of angles is of particular interest since it is here that departure from S-wave scattering is indicated.[1] For K^+-p scattering and for K^+-n charge-exchange scattering assuming even K^0-K^+ relative parity, the polarization would exhibit the same transverse nature as observed in nucleon-nucleus elastic scattering. However, for odd K^0-K^+ relative parity, the recoil proton would exhibit a different polarization perpendicular to the plane of scattering in the latter case. The information to be obtained from the proposed experiment concerning the K^0-K^+ relative parity and nature of the scattering amplitude will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Lannutti, Goldhaber, Goldhaber, Chupp, Giambuzzi, Marchi, Quarini, and Wataghin, Phys. Rev. 109, 2121 (1959).

XA2. Low-Energy K^- Interactions in Hydrogen.* P. NORDIN, A. H. ROSENFELD, F. T. SOLMITZ, R. D. TRIPP, AND M. B. WATSON, *University of California, Berkeley.*—In an experiment performed with the Berkeley 15-in. hydrogen bubble chamber we have observed 5500 K^--p absorptions from atomic states and about 1200 interactions in flight in the moment range from 0 to 400 Mev/c. The latter consist of elastic and charge-exchange scattering and hyperon production. We have previously reported preliminary values of the cross sections for these reactions[1]; further analysis of the data has modified these appreciably. Our values for the elastic cross sections now are: $50<P_{K\ \mathrm{lab}}<100$ Mev/c, $\sigma_{el}=70\pm22$ mb; 100 to 150 Mev/c, $\sigma_{el}=92\pm15$ mb, 150 to 200 Mev/c, $\sigma_{el}=86\pm11$ mb; 200 to 240 Mev/c, $\sigma_{el}=51\pm13$ mb; 290 to 310 Mev/c, $\sigma_{el}=52\pm7$ mb; 395 to 425 Mev/c, $\sigma_{el}=43\pm5$ mb. Further cross sections and a phenomenological analysis will be presented.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] 1958 Annual Conference on High-Energy Physics at CERN, Geneva, 1958; Bull. Am. Phys. Soc. Ser. II, 3, 336, 363 (1958); 4, 24 (1959).

XA3. Decay of K^- Mesons.* C. MELTZER, M. M. BLOCK, B. BRUCKER, AND T. KIKUCHI, *Duke University*, A. PEVSNER, F. ANDERSON, AND A. THORNDIKE, *Johns Hopkins University*, H. O. COHN, *Oak Ridge National Laboratory*, E. HARTH AND J. LEITNER, *Syracuse University.*—Exposures of the Duke University helium bubble chamber to the slow K^- beam of the Berkeley bevatron have been scanned for K^- decays in flight. A preliminary sample has yielded to date about 300 K^- decays among a total of about 3000 K^- traversals of the chamber. The observed τ branching ratio of about 5% is in good agreement with the K^+ results.[1] Data on other branching ratios and lifetime of the K^- will be presented.

* This work was supported by the U. S. Atomic Energy Commission, the Office of Naval Research, and the Office of Scientific Research.
[1] Whitehead, Stork, Peterson, Perkins, and Birge, University of California Radiation Laboratory, UCRL-3295 (1956).

XA4. ΛK Production near the Σ Threshold.* LUCIANO FONDA† AND ROGER G. NEWTON, *Indiana University.*—It was suggested last year by Adair[1] that the relative $\Lambda\Sigma$ parity may be obtained experimentally by observing the production of Λ's and K's by pions in the vicinity of the threshold for the production of Σ's. If the Λ and Σ parities are equal then one may expect a cusp (or rounded step), but if they are unequal, the anomaly is probably too small to be observable. This prediction follows at once from the fact that the cusp-producing term is proportional to the matrix element from the s wave of the Σ channel to the s wave in the Λ channel if the $\Lambda\Sigma$ parity is even and to the p wave in the latter if it is odd,[2] together with the assumption that near the Σ threshold the p wave in the Λ channel is much weaker than the s wave. We have made explicit calculations of the Λ production cross-section curve on the assumption of square-well scattering and production potentials. The purpose is to see how sensitive the size of the cusp in the case of equal parities is to the strengths of the interactions and if in fact the anomaly could lend itself to the experimental determination of the relative $\Lambda\Sigma$ parity. The resulting curves will be presented.

* Supported in part by the National Science Foundation.
† On leave of absence from Trieste University on a Fulbright Traveling Grant.
[1] R. K. Adair, Phys. Rev. 111, 632 (1958).
[2] R. G. Newton, Phys. Rev. (to be published).

XA5. Energy and Angular Distributions of Mesonic Hyperfragment Decays. N. BYERS, *Stanford University,* AND W. N. COTTINGHAM, *University of Birmingham.*—Angular and energy distributions for the decay $_{\Lambda}He^{5} \rightarrow \pi^{-}+p+He^{4}$ have been calculated neglecting pion interactions. The calculation shows that the angular asymmetry observed in three-pronged hyperfragment decays of this type can result from low-energy nuclear resonances (compound nucleus formation). The energy and angular distributions for the $_{\Lambda}He^{5}$ decay will be presented. The form of these curves is largely determined by the 1.8-Mev P_1 resonance seen in proton-He^4 scattering. Effects due to parity violation and pion interactions will be discussed. It is found that they will not produce any significant qualitative effects.

XA6. Nonmesonic Decay Modes of $_{\Lambda}He$.* S. LIMENTANI, P. SCHLEIN, P. STEINBERG, AND J. ROBERTS, *Northwestern University.*—525 possible nonmesonic hyperfragment decays have been found among the secondary interactions from 17 000 stopping K^- stars in a stack of Ilford K-5 and L-4 emulsion. The exposure and the scanning are the same reported in the NU contribution to the EFINS-NU collaboration experiment[1] on π^- mesonic hyperfragment decays. An effort is being made to select a bias-free sample of $_{\Lambda}He$ non mesonic hyperfragments and to deduce such information as the nonmesonic/mesonic decay ratio[2] and the relative frequencies of the various nonmesonic decay modes.[3] Such an attempt includes a rescanning in which particular attention is being paid to the detection of possible examples of the one-prong nonmesonic decay mode: $_{\Lambda}He^{5} \rightarrow He^{3}+2N$. In the single-nucleon stimulated decay model,[4] this mode should represent a considerable fraction of the decays. Track-thickness ionization (profile) measurements with improved equipment are employed.

* This work was supported by the National Science Foundation and the U. S. Atomic Energy Commission through Argonne National Laboratory subcontract.
[1] Ammar, Levi-Setti, Limentani, Roberts, Schlein, Slater, and Steinberg, Bull. Am. Phys. Soc. Ser. II, 3, 175 (1958).
[2] R. H. Dalitz, Phys. Rev. 112, 605 (1958); "Strange particle decay processes and the Fermi interaction," Revs. Modern Phys. (to be published).
[3] P. Schlein, "Non-mesonic/mesonic decay ratio of helium hyperfragments," Phys. Rev. Letters (to be published). Thirty-three two pronged nonmesonic ΛHe events with connecting tracks $\geq 50\,\mu$ found in this stack are considered here.
[4] M. Baldo-Ceolin *et al.*, Nuovo cimento 7, 328 (1958).

XA7. On the Discrepancy of the Lifetime of the Σ^+ Hyperon.* M. F. KAPLON, T. YAMANOUCHI, AND A. C. MELISSINOS, *University of Rochester.*—An investigation of the lifetime of the Σ^+ hyperon decaying by the $p+\pi^0$ mode in emulsions has been made. A Monte Carlo type calculation confirmed the consistency of the maximum likelihood estimation for this range of lifetimes and potential times. Using data from Rochester, Wisconsin,[1] and Livermore,[2] the actual likelihood curves for 94 events have been calculated on an IBM 650. From decays in flight and at rest we obtain (a) $\tau=0.87\times10^{-10}$ sec, while two-parameter analyses yield (b) $\tau_1=0.54$ and $\tau_2=1.21$; the ratio of the likelihoods is $L_b/L_d=1.21$. From D.I.F. only we obtain $\tau=0.50$ while energy cutoffs at 10, 19, and 27 Mev yield $\tau=0.26$, 0.25, and 0.25×10^{-10} sec, respectively.

* This research supported in part by the Office of Scientific Research U. S. Air Force, and the U. S. Atomic Energy Commission.
[1] Fry *et al.*, Phys. Rev. 107, 257 (1957).
[2] Gilbert, Violet, and White, Phys. Rev. 107, 228 (1957); and unpublished data.

XA8. Σ^- Hyperon Absorption in Deuterium.* NAHMIN HORWITZ, DONALD MILLER, AND JOSEPH MURRAY, *University of California, Berkeley.*—In a recent exposure of the Berkeley deuterium chamber to the separated K^--meson beam, 2300 interactions involving the production of hyperons were obtained. In 28 events of the type $K^-+D \rightarrow \Sigma^-+\pi^++n$ (group A), Λ's were observed from the subsequent absorption of the Σ^- hyperons via the reactions $\Sigma^-+D \rightarrow \Sigma^0$ (or Λ)$+n+n$. In addition, 30 Λ's were produced in the absorption of Σ^-'s from the reaction $K^-+D \rightarrow \Sigma^-+p+\pi^0$ (group B). The latter group contains a contamination of indistinguishable events arising from the absorption of K^- mesons via the reactions $K^-+D \rightarrow \Sigma^0$ (or Λ)$+\pi^0+n$ after an inelastic K^--D scatter. Since the Q value associated with the Σ-Λ conversion is 80 Mev, Λ's produced directly are readily separated from the low-momentum Λ's (<134 Mev/c) resulting from Σ^0 decay. For the 51 events thus far measured we find $7\Sigma^0$'s and 44 direct Λ's, giving the value 0.14 ± 0.06 for the $\Sigma^0/(\Sigma^0+\Lambda)$ branching ratio. The Λ spectrum resulting from the background events in group B is such that this number represents an upper limit. The results are to be compared with the corresponding branching ratio, 0.33 ± 0.05, for the reactions $\Sigma^-+p \rightarrow \Sigma^0$ (or Λ)$+n$. The additional conversions may be related to the two-step process observed in the reaction $K^-+D \rightarrow \Lambda+\pi^-+p$.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

XA9. Search for Particles of Mass $500m_e$ with Decay Scheme $500 \rightarrow \pi^0+\mu^+$.* R. GIACCONI, H. GURSKY,† AND A. HENDEL,‡ *Princeton University.*—A search has been made for long-lived charged particles of mass $500m_e$ in the cosmic radiation at sea level. Particles heavier than muons stopping and decaying in a plastic scintillator are selected. The decay is required to occur between 10^{-4} and 50×10^{-6} sec and be followed by another decay within 6×10^{-6} sec. Estimates on the mass of the stopping particles are obtained by dE/dx and E measurements. Preliminary results show that the upper limit of the ratio of the number of mass 500 particles to muons in the same range interval is $\sim2\times10^{-4}$.

* Supported by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at Columbia University.
‡ Now at University of Michigan.

XA10. Monte Carlo Calculation of Strange-Particle Production.* L. SARTORI AND A. E. WERBROUCK, *Princeton University,* J. K. WOOTEN AND R. L. BIVINS, *Los Alamos Scientific Laboratory.*—The production of hyperons and K mesons by pions and nucleons incident on heavy nuclei is being calculated by a Monte Carlo technique, employing the Los Alamos Maniac II computer. Use is made of experimental cross

sections whenever available. In each interaction the incident particle may scatter elastically, produce one or more pions, or produce strange particles. If a nucleon produces a pion above threshold for Λ production, the pion is then followed. When a strange-particle pair is produced, each member is allowed to interact with nucleons until it either emerges from the nucleus or (in the case of a Λ) is captured to form a hypernucleus. Account is taken of the motion of the target nucleons, and of the effect of the Pauli principle. A substantial fraction of the strange particles is produced in secondary interactions, especially in the heavier nuclei. For incident protons this may be the dominant mode of production (i.e., through an intermediate pion). The results are to be compared with experimental data of the Princeton cloud chamber group, as well as others. Preliminary analysis indicates a reasonable consistency with the Princeton data.

* Supported by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.

SATURDAY AFTERNOON AT 1:30

National Bureau of Standards, East Building

(G. H. DIEKE presiding)

Molecular Spectra

Y1. Hyperfine Structure in the Rotational Spectra of Free Radicals.* JOHN G. BAKER, *Duke University* (introduced by W. Gordy).—A classical approach is used to derive the Hamiltonian for hyperfine interactions between rotation, unpaired electronic spins and nuclear spins in molecules of the free radical type. The method of Van Vleck[1] is then applied in order to insert these interactions into the secular determinant giving the rotational energy levels. A slight modification in the normal diagonalization of the asymmetric rotor energy levels results in determinants of order up to $(2S+1)$ for the hyperfine energy splittings corresponding to each value of the total angular momentum F. It is also possible to determine the Stark and Zeeman effects in the presence of this hyperfine structure. This theory has been used to give a partial explanation of the published microwave spectrum[2] of NO_2, and also in microwave studies[3] of ClO_2, the only remaining stable free radical for which no accurate structural determination exists. Further work on these two gases is now in progress in the millimeter wave region to obtain more detailed information about their molecular structure.

* Work supported by the Office of Scientific Research, U. S. Air Force.
[1] J. H. Van Vleck, Revs. Modern Phys. **23**, 213 (1951).
[2] G. R. Bird, J. Chem. Phys. **25**, 1040 (1956); Bull. Am. Phys. Soc. Ser. II, **4**, 68 (1959).
[3] J. G. Baker, Ph.D. dissertation, Cambridge University (1958).

Y2. Electron Spin Resonance Spectra of Free Radicals Trapped in Polymethacrylic Acid after Gamma Irradiation at 77°K.* DERICK W. OVENALL, *Duke University* (introduced by W. Gordy).—After gamma irradiation at 300 °K polymethacrylic acid gives an ESR spectrum consisting of a quintet with a weaker intermediate quartet, which has been attributed to trapped propagating radicals with structure $-CH_2-\dot{C}(CH_3)CO_2H$.[1] When polymethacrylic acid is gamma irradiated at 77°K the ESR spectrum at this temperature is a septet, which changes irreversibly into the room temperature spectrum on warming. Samples of polymethacrylic acid freed from monomer give only a single line spectrum when irradiated and observed at 77°K. It is suggested that one primary effect of irradiation at 77°K is removal of the side chains to give $\cdot CO_2H$ radicals. Many of these decompose into carbon dioxide and hydrogen atoms. When polymer freed from monomer is irradiated at 77°K the hydrogen atoms recombine, leaving some trapped $\cdot CO_2H$ radicals which give the single line spectrum. If the polymer contains monomer, the hydrogen atoms will add to this to give radicals of structure $(CH_3)_2C-CO_2H$, which could give rise to the septet observed at 77°K. At room temperature, addition of monomer molecules to these radicals results in the production of propagating radicals.

* This research was supported by the Office of Ordnance Research, Department of the Army.
[1] Abraham, Melville, Ovenall, and Whiffen, Trans. Faraday Soc. **54**, 1133 (1958).

Y3. Electron Spin Resonance of Free Radicals Formed by Irradiation of Amino Acids and Proteins at 77°K.* FRANK PATTEN AND WALTER GORDY, *Duke University*.—When γ irradiated and observed at 77°K, many amino acids, peptides, and proteins were found to give electron spin resonance patterns which differ markedly from those obtained when the samples were irradiated at 300°K and then cooled to 77°K. When certain of these samples irradiated at 77°K were allowed to warm, their patterns at 300°K were found to become like those obtained by irradiation at 300°K. When these samples were cooled again to 77°K, they did not regain their original patterns. From these results we conclude that temperature often influences strongly the kind of radicals produced or stabilized in organic solids and that the radicals observed at room temperature are often not the primary ones produced by the irradiation.

* Work supported by the Office of Scientific Research, U. S. Air Force.

Y4. Millimeter-Wave Rotational Spectrum of NO in the $^2\pi_{\frac{1}{2}}$ State.* PAOLO G. FAVERO,† ANNA M. MIRRI, AND WALTER GORDY, *Duke University*.—The $J=\frac{3}{2}\rightarrow\frac{1}{2}$ rotational transition of NO in the $^2\pi_{\frac{1}{2}}$ electronic state has been measured in the 1.17-mm wave region. Theory applied to these measurements combined with previous measurements on transitions of the ground $^2\pi_{\frac{1}{2}}$ state lead to the following values for the characteristic constants of $N^{14}O^{16}$: The rotational constant, $B_0=50\,848.42$ Mc/sec, and the spin-orbit coupling constant $A=122.094$ cm^{-1}. The N^{14} nuclear magnetic couplings $a=83.82$ Mc/sec, $b=68.49$ Mc/sec, $c=-86.34$ Mc/sec, and the N^{14} nuclear quadrupole couplings $eQq_1=-2$ Mc/sec, $eQq_2=22$ Mc/sec. The Λ-doubling constants $p_\Lambda=175.15$ Mc/sec, $q_\Lambda=1.15$ Mc/sec.

* This research was supported by the Office of Scientific Research, U. S. Air Force.
† International Fellow of the National Academy of Sciences through International Cooperation Administration.

Y5. Oxygen Vibration and Dissociation Relaxation Rates.* A. VAUGHAN AND M. CAMAC, *Avco Research Laboratory*.—The rates of vibrational excitation and dissociation relaxation of molecular oxygen were measured in normal-shock heated 1% oxygen-99% argon mixtures. Data were obtained over

the temperature range from 1500 to 7600°K. The concentration of O_2 was determined by its absorption of radiation in the (1470 A) Schumann-Runge region. Dissociation was observed to occur via the reaction $A+O_2 \rightarrow O+O+A$ over the temperature range from 3500 to 7600°K, with a rate constant for this reaction given by $4.5\times10^{14}(5000/T°K)^{1.5}\times\exp(-59000/T°K)$ cc²/mole²-sec, where the exponent corresponds to the binding energy of 5.1 ev. Observations below 4200°K show that dissociation proceeds at a rate lower than this value until vibrational excitation is essentially complete. This is consistant with the assumption that dissociation occurs from all vibrational levels of the oxygen molecule. The vibrational excitation of O_2 by A has the same temperature dependence as for excitation by O_2, and a cross section ⅓ of that for O_2.

* This work was sponsored by the Ballistic Missile Division, Air Research and Development Command, U. S. Air Force.

Y6. Air Opacity Measurements.* D. E. BUTTREY, *Lockheed Aircraft Corporation.*—Time resolved spectra of shock-heated O_2 reveal an emission continuum attributed to O^- covering the entire visible range of wavelengths for the conditions of approximately 10 000°K and one-half normal density. From preliminary analyses of the data, photoelectric cross sections have been obtained for the wavelengths between 3500 and 6000 A. Spectrographic data obtained for N_2 under essentially the same conditions of temperature and density reveal the (0,0), (1,0) vibrational systems of the N_2 second positive system. Photomultiplier-scope traces for a 40-A band pass at 3350 A reveal the time history of the radiation for both O^- and N_2 where the reflected shock is viewed perpendicular to the direction of motion.

* This work was supported by the U. S. Air Force Cambridge Research Center.

Y7. Microwave Spectrum of Propane. DAVID R. LIDE, JR., *National Bureau of Standards.*—Several weak absorption lines have been observed in propane, C_3H_8. The majority of the lines can be assigned as rigid asymmetric rotor transitions with rotational constants 29207.4, 7459.0, and 8446.0 Mc. If the C-H parameters are assumed, these constants indicate a CC distance of 1.536 A and a CCC angle of 111°40′. Stark effect measurements give a dipole moment of $0.081D$. The observation of a rigid-rotor spectrum indicates that the barrier to internal rotation of a CH_3 group is greater than 3000 cal/mole.

Y8. Theory of the Stark Effect and Hyperfine Structure for Near-Degenerate Energy Levels of an Asymmetric Rotor. D. F. EAGLE, T. L. WEATHERLY, AND J. Q. WILLIAMS, *Georgia Institute of Technology.*—The theory of the Stark effect in the presence of quadrupole interaction has been extended to cover the case of closely spaced asymmetric top energy levels. A straightforward matrix formulation of the problem was used in which the Stark and quadrupole interaction perturbations were simultaneously included. The contact transformation employed by Golden and Wilson[1] was applied to the Hamiltonian in order to facilitate the diagonalization process. Predictions of the absorption line frequencies for the $2_1 \rightarrow 3_0$ transition in nitryl chloride according to this theory agree well with the measured values at seven different Stark voltages for an assumed dipole moment of 0.53 debye. This approach will be compared with the method of Mizushima[2] using the degenerate calculation of Stark energies instead of the nondegenerate.

[1] S. Golden and E. B. Wilson, Jr., J. Chem. Phys. 16, 669 (1948).
[2] M. Mizushima, J. Chem. Phys. 21, 539 (1953).

Y9. Stark Effect for Near-Degenerate Rotational Levels of NOCl. E. L. BEESON,* J. Q. WILLIAMS, AND T. L. WEATHERLY, *Georgia Institute of Technology.*—The Stark effect of the $J_\tau = 1_1 \rightarrow 2_0$ transition of $NOCl^{35}$ has been analyzed. At the high field intensities used the nuclear quadrupole interactions may be treated as small perturbations on the eigenstates of the rotational plus Stark effect Hamiltonian. Quadrupole splitting of the Stark components was not resolvable. Stark splittings were calculated by the theory of Golden and Wilson[1] treating the 1_1 and 1_0 levels and the 2_0 and 2_{-1} levels as degenerate. The observed Stark splittings are in good agreement with the calculated splittings for a dipole moment $\mu_a = 1.86\pm0.02$ debye. The component μ_b does not contribute a measurable splitting and cannot be determined, and the component μ_c is zero for the planar molecule. This value of μ_a differs appreciably from Rogers' estimate of 1.28 debye[2] but compares favorably with the value 1.83 debye reported for the total dipole moment in a solution of carbon tetrachloride.[3]

* Supported by grant from the Southern Fellowships Fund.
[1] S. Golden and E. B. Wilson, Jr., J. Chem. Phys. 16, 669 (1948).
[2] Rogers, Pietenpol, and Williams, Phys. Rev. 83, 431 (1951).
[3] L. G. Wesson, *Tables of Electric Dipole Moments* (Technology Press, Cambridge, Massachusetts).

Y10. Hyperfine Structure in Rotational Transitions of Fluorotrichloromethane.* M. W. LONG, J. Q. WILLIAMS, AND T. L. WEATHERLY, *Georgia Institute of Technology.*—The $J=1 \rightarrow 2$ and $J=2 \rightarrow 3$ transitions of $CFCl_3^{35}$ have been investigated. The spectra occur at 9.86 and 14.79 kMc; the absorption coefficients for the stronger lines in the $J=1 \rightarrow 2$ transition are about 10^{-9} cm^{-1}. The $J=1 \rightarrow 2$ spectrum was compared with a theoretical calculation similar to that made by Wolfe[1] for the $J=2 \rightarrow 3$ spectrum of chloroform. The calculation results in 11 energy levels for $J=1$ and 16 for $J=2$; there are 99 possible transitions. The $J=2 \rightarrow 3$ spectrum was compared with Wolfe's calculations. This analysis gives the quadrupole coupling constant with respect to the molecular symmetry axis $eQV_{zz} = 37.3\pm0.5$ Mc and the centrifugal distortion constant $D_{JK} = -196\pm4$ kc. The rotational constant, exclusive of the effect of distortion constant D_J, was determined to be $B = 2465.19\pm0.01$ Mc by using the $J=1 \rightarrow 2$ data and the above value of D_{JK}. Transitions $J=3 \rightarrow 4$ through $J=6 \rightarrow 7$ are being investigated in an effort to determine D_J.

* This work was supported in part by the Office of Naval Research.
[1] P. N. Wolfe, J. Chem. Phys. 25, 976 (1956).

Y11. Microwave Spectrum and Internal Rotation of Ethyl Cyanide. VICTOR W. LAURIE,* *National Bureau of Standards.*—The microwave spectrum of ethyl cyanide has been studied in the region from 17 to 35 kmc. Both parallel and perpendicular transitions have been identified and measured. Rotational constants (Mc) for the ground vibrational state are $a_0 = 27663.30$, $b_0 = 4714.14$, $c_0 = 4235.14$, $D_J = 0.0035$, and $D_{JK} = -0.0496$. From Stark effects the dipole moment is calculated to be $4.02D$. Hyperfine splittings lead to a value of -3.3 Mc for the quadrupole coupling of the N^{14} nucleus along the a axis. Rotational transitions of molecules in several excited vibrational states have also been measured. A coriolis interaction between the torsional mode and the symmetric CCN bend has been found. Splittings of transitions of molecules in the first excited torsional state show that the barrier hindering internal rotation of the methyl group is 3.11 kcal/mole.

* National Research Council-National Bureau of Standards Research Associate (1957–1959).

Y12. Infrared Spectra of Solid Ammonia. P. A. STAATS AND H. W. MORGAN, *Oak Ridge National Laboratory.*—The infrared spectra of thin films of solid NH_3 and ND_3 have been studied as a function of temperature and of the conditions under which the films were deposited. Observations of the spectra were made at prism resolution, using a low-temperature cell of conventional design. Spectra have been obtained

from the two metastable phases reported by the x-ray studies of Mauer and McMurdie,[1] and from the cubic stable phase. The metastable phases were prepared by the deposition of solid films at 77 and 112°K. The stable modification was obtained by deposition at 160°K, and its spectrum studied at temperatures down to 77°K. The spectrum of the stable phase is in good agreement with that predicted from the established cubic structure.[2] No evidence was observed of inversion doubling in any phase. A reversal of intensities for ν_1 and ν_3 was observed between the gaseous and solid states; this will be discussed in terms of the intermolecular bonding in the solid.

[1] F. A. Mauer and H. F. McMurdie, presented at the 1958 meeting of the American Crystallographic Association, Milwaukee, Wisconsin.
[2] J. de Smedt, Bull. class. sci. Acad. roy. Belg. 11, 655 (1925); H. Mark and E. Pohland, Z. Krist. 61, 532 (1925).

SATURDAY AFTERNOON AT 1:30

Willard, South Ballroom

(R. L. HAYWARD presiding)

Radioactive Nuclei, II

YA1. Electron Capturing Isotopes of Pm Produced by Proton Irradiation of Nd. E. G. FUNK, JR., J. W. MIHELICH, AND C. F. SCHWERDTFEGER, *University of Notre Dame,** AND B. HARMATZ, *Oak Ridge National Laboratory.*†—We have studied the decay of long-lived Pm^{145}, Pm^{144}, and Pm^{146} produced by proton irradiation of enriched Nd isotopes. We confirm the findings[1] that Pm^{145} decays via electron capture to a level of 745 kev in Nd^{145}, and that Pm^{144} electron captures to levels of 695, 1315, and 1790 kev in Nd^{144}. Our angular correlation experiments are consistent with spins of 2, 4, and 6 for these levels in agreement with Ofer's results.[1] Pm^{146} ($T_{\frac{1}{2}}>100$ days) decays to levels of 450 and ~1200 kev in Nd^{146}. The only gamma rays of appreciable intensity are those of 450 and 750 kev. Angular correlation measurements are in progress.

* Supported by the U. S. Atomic Energy Commission.
† Operated for the U. S. Atomic Energy Commission by Union Carbide Nuclear Company.
[1] S. Ofer, Phys. Rev. (to be published).

YA2. Decay of Eu^{152m}.* R. E. SUND, R. G. ARNS, AND M. L. WIEDENBECK, *University of Michigan.*—The gamma rays in Sm^{152} and Gd^{152} following the decay of the 9.3-hr metastable state of Eu^{152} have been studied in permanent magnet spectrographs. A number of new weak transitions have been observed, and a decay scheme is proposed. Directional correlation measurement have been made on two cascades in Sm^{152} and on one cascade in Gd^{152}. The measurements confirm the spin and parity assignments of 1− and 2+ for the 0.963-Mev and 0.122-Mev levels in Sm^{152}.[1] Possible spin assignments for the 1.511-Mev level in Sm^{152} will be discussed. The 1.315-Mev and 0.344-Mev levels in Gd^{152} have a spin and parity of 1− and 2+, respectively. Multipolarities will be given for the principal gamma transitions.

* Supported in part by the Michigan Memorial Phoenix Project and the U. S. Atomic Energy Commission.
[1] G. T. Wood and O. Nathan, submitted to the International Congress on Nuclear Physics, Paris (1958).

YA3. Vibrational Levels in Dy^{160}. G. T. EWAN, R. L. GRAHAM, AND J. S. GEIGER, *Chalk River Laboratories.*—The β-ray spectrum of Tb^{160} has been studied at 0.1% resolution in an air-cored $\pi\sqrt{2}$ β-ray spectrometer. Conversion lines were observed corresponding to γ rays of energies 86.7($E2$), 93.6 ($M1+E2$), 196.9(E_2), 215.5($E1$), 298.3($E1$), 309.4, 392.2($E1$), 682.1, 764.8, 879.0($E2$), 961.9($E2$), 965.7($E2$), 1115.0, 1177.7 ($E1$), 1199.9($E1$), 1271.4($E1$), and 1312.2($E1$) kev. Multipolarity assignments are based on conversion line intensity ratios for low-energy γ rays and conversion coefficients[1] for high-energy γ rays. Our results indicate levels in Dy^{160} at 0(0+), 86.7(2+), 283.6(4+), 965.7(2+), 1048.5(3+), 1264.2 (2−), 1358.0(3−), and 1398.8(3−) kev. The relative transition intensities confirm Nathan's[2] postulate of a $K=2$ quadrupole vibrational band, 965.7(2+) and 1048.5(3+), and of a $K=2$ octupole vibrational band, 1264.2(2−) and 1358.0(3−). A search for the $3+\rightarrow 2+(K=2)$ 82.8 kev transition shows its intensity is less than 3×10^{-4} of the interband $3+(K=2)\rightarrow 2+(K=0)$ 961.9 kev transition. The weak 1199.9($E1$) transition indicates a level at either (a) 1199.9(1−) or at (b) 1286.6 (1,2,3−). The experimental data preclude a $K=0(-)$ assignment for postulate (a).

[1] M. A. Clark and J. W. Knowles, Bull. Am. Phys. Soc. Ser. II, 2, 231 (1957), and unpublished results.
[2] O. Nathan, Nuclear Phys. 4, 125 (1957).

YA4. Decay of Dy^{165} and Dy^{165m}.* F. P. CRANSTON, JR., J. W. STARNER, AND M. E. BUNKER, *Los Alamos Scientific Laboratory.*—The radiations of Dy^{165} ($T_{\frac{1}{2}}=2.36\pm0.01$ hr) and Dy^{165m}($T_{\frac{1}{2}}=1.25\pm0.01$ min) have been investigated with β and γ scintillation spectrometers, a solenoidal β-ray spectrometer, and a 180° permanent-magnet spectrograph. The principal β groups of Dy^{165} have end-point energies and intensities of 1.19 Mev (14%) and 1.28 Mev (84%), the latter being the ground-state transition. γ transitions were observed with energies of 94.7($M1+E2$), 279.4($M1$), 361.0($M2$), 480, 515, ~545, 564, 620, 634, 715, 900, 995, and 1080 kev. Dy^{165m} decays either by a 108-kev isomeric transition (97%) or by a 0.87-Mev β transition (3%). The β transition is followed by γ rays of energies 156, 361, and 515 kev. The foregoing data, together with the results of β-γ and γ-γ coincidence studies, suggest the existence of the following nuclear levels in Ho^{165}: 94.7, 361.0, 515, 715, 995, 1080 kev. The half-life of the 361.0-kev level was measured to be 1.51 ± 0.01 μsec. An interpretation of the observed levels in terms of the Nilsson model will be given.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

YA5. Radioactive Isotopes of Lutecium. R. G. WILSON AND M. L. POOL, *Ohio State University.*—Lutecium isotopes of mass numbers 170, 171, 172, 173, and 174 were produced from the enriched isotopes of ytterbium. By identification of the Yb K x-ray these five Lutecium isotopes decay by electron capture. Prominent Yb L x-rays also exist in the 170 and 171 activities. The half-life of the Lu 170 activity measured through four half-lives is 2.3 days. The previously reported value is 1.7 days. An 84-kev gamma exists in this activity and the decay is primarily to the ground state. The half-life of the 171 activity measured through five half-lives is 8.0 days. The previously reported value is 8.5 days. This activity consists of a strong 743-kev gamma and two weaker lines of 116 and 678 kev in coincidence. Approximately two-thirds of the

transitions occur to the ground state. The activity of Lu 172 includes gammas of 180, 805, 910, and 1100 kev. The latter two are in coincidence. Gamma energies of 79, 101, 172, and 273 kev exist in Lu 173. The 79 and 273-kev lines are in coincidence. Lu 174 decays primarily to the ground state. The previously reported 4.0-hr positron activity of Lu 172 can best be attributed to an impurity.

YA6. Decay of Ta^{182m}.* R. G. ARNS, R. E. SUND, AND M. L. WIEDENBECK, *University of Michigan*.—The 16.5-min metastable state of Ta^{182} decays by gamma emission to the Ta^{182} ground state and by beta emission to the excited states of W^{182}. Three gamma rays have been observed with energies of 0.180 Mev, 0.160 Mev, and 0.340 Mev (crossover transition).[1] Angular correlation measurements have been made on the 0.180-Mev–0.160-Mev cascade. Assuming a spin and parity of 3− for the Ta^{182} ground state, the resultant expansion coefficients, internal conversion data, and summing crystal spectra are consistent with a $7(M3)4(93.2\pm0.8\%\ E1, 6.8\mp0.8\%\ M2)3$ sequence. Other possible spin assignments will be discussed and the corresponding gamma ray multipolarities will be given.

* Supported in part by the Michigan Memorial Phoenix Project and the U. S. Atomic Energy Commission.
[1] F. C. Chang, thesis, University of Michigan (1958).

YA7. Alpha Decay of Light Astatine Isotopes.* RICHARD W. HOFF, FRANK ASARO, AND ISADORE PERLMAN, *University of California, Berkeley and Livermore*.—Utilizing a double-focusing magnetic alpha-particle spectrograph, the energies, half-lives, and relative intensities of the alpha groups of astatine isotopes with masses 201 to 207 were measured as follows: At^{201}, $t_{\frac{1}{2}}=1.5\pm0.1$ min, $E_\alpha=6.348$ Mev; At^{202}, $t_{\frac{1}{2}}=3.0\pm0.2$ min, $E_\alpha=6.231$ Mev (36%), $E_\alpha=6.133$ Mev (64%); At^{203}, $t_{\frac{1}{2}}=7.4\pm0.3$ min, $E_\alpha=6.086$ Mev; At^{204}, $t_{\frac{1}{2}}=9.3\pm0.3$ min, $E_\alpha=5.950$ Mev; At^{205}, $t_{\frac{1}{2}}=26.2\pm0.5$ min, $E_\alpha=5.899$ Mev; At^{206}, $t_{\frac{1}{2}}=21.7\pm2.6$ min, $E_\alpha=5.699$ Mev; At^{207}, $t_{\frac{1}{2}}=1-4$ hr, $E_\alpha=5.750$ Mev. To produce these astatine isotopes, gold foil targets were bombarded with C^{12}, N^{14}, and O^{16} ions accelerated in the Heavy Ion Linear Accelerator. No evidence has been found for the alpha decay of the 25-min At^{204} and the 2.9-hr At^{206} electron-capturing isotopes reported by Barton, *et al.*[1] and Stoner.[2] Alpha-gamma coincidence measurements have shown a photon of approximately 68-kev energy to be in coincidence with the 21.7-min At^{206} alpha particles. Upper limits were obtained for photons in coincidence with the other alpha groups studied. Correlation of these alpha decay properties with alpha decay systematics will be presented.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] Barton, Ghiorso, and Perlman, Phys. Rev. **82**, 13 (1951).
[2] A. W. Stoner, Ph.D. thesis, University of California Radiation Laboratory Report UCRL-3471, June, 1956 (to be published).

YA8. Decay Scheme of Np^{234}. C. J. GALLAGHER, JR., *California Institute of Technology*, AND T. D. THOMAS, *University of California, Berkeley*.—Transitions following the *EC* decay of 4–4 day Np^{234} have been investigated with 99-, 160-, and 350-gauss permanent magnets, a solenoidal "long lens" spectrometer, and NaI (Tl) scintillation detectors with a 100-channel analyzer. Many internal-conversion electron lines were observed, and assigned to transitions at 43.49, 99.70, 233.6, 234.6, 247.9, 450.5, 517.0, 525.9, 558.0, 743.3, 750.9, 767.2, 787.0, 793.0, 809.1, 810.6, 853.1, 1002, 1103, 1194, 1237, 1393, 1437, 1529, 1560, 1572, and 1604 kev. Other weak internal conversion lines were also observed. Transitions following Np^{236}, Np^{238}, and Np^{239} decay were also observed on the same plates and identified, helping to insure correct isotopic assignment. The above transitions can be interpreted to establish levels of U^{234} at 43.5, 143.2, 787, 809, 853, 1237, 1437, 1572, and 1604 kev. Other levels can be postulated also, but with less certainty. The 810-kev *EC* transition has been resolved into two components and this, transition multipolarities, and possible level spin and parity assignments will be discussed.

YA9. Beta Decay of Bk^{250} and Bk^{249}.* SUSANNE E. VANDENBOSCH, HERBERT DIAMOND, RUTH K. SJOBLOM, AND PAUL R. FIELDS, *Argonne National Laboratory* (introduced by F. T. Porter).—The beta decay of Bk^{250} has been studied with a beta spectrometer. Bk^{250} has two beta groups: 725 ± 15 kev ($89\pm1\%$ abundant) and 1760 ± 50 kev ($11\pm1\%$ abundant). Conversion electron lines corresponding to 42.2-, 98.2-, 890-, 930-, 990-, and 1032-kev transitions were observed and their intensities measured. The information obtained from crystal spectrometer singles and coincidence measurements was combined with beta spectrometer data to construct a decay scheme for Bk^{250} involving gamma vibrational levels in Cf^{250} analogous to those found in Pu^{239}. The beta half-life of Bk^{250} is 193.3 ±0.3 min. The electron capture partial half-life of Bk^{250} is estimated to be greater than 5 years. The beta spectrum of Bk^{249} shows an allowed or first forbidden transitions with an end-point energy of 125 ± 2 kev.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

SATURDAY AFTERNOON AT 1:30

Room B in Departmental Auditorium

(P. G. BERGMANN presiding)

Theory, VI: Relativity

Z1. Construction of Four Vectors. T. ERBER,* *Illinois Institute of Technology*.—The heuristic value of covariant formalism has been stressed since the early days of (special) relativity.[1] Nevertheless, the ideas involved in one of the commonest tools of covariant calculation, the four vector, seem to lack somewhat in clarity and generality; specifically, there does not seem to be an algorithm for constructing the four vector associated with a given three vector. We shall present a definition for four vectors which leads immediately to such an algorithm—stated in terms of functional equations. The method will be illustrated by means of several examples.

* I.I.T. Faculty Research Fellow.
[1] R. Kretschmann, Ann. Physik **53**, 575 (1917); A. Einstein, Ann. Physik **55**, 241 (1918).

Z2. Non-Lorentzian Form of Special Relativity. BENJAMIN LIEBOWITZ, *350 Fifth Avenue, New York*.—A theory of special relativity is proposed based on the following transformation system: (*Ia*), $x'=\Gamma(x-vt)$, $t'=\Gamma(t-vx/c^2)$; *in*verse of (Ia),

viz. (Ib), $x=(\gamma^2/\Gamma)(x'+vt')$, $t=(\gamma^2/\Gamma)(t'+vx'/c^2)$; *re*verse of (Ia), *viz.* (IIa), $x=\Gamma(x'+vt')$, $t=\Gamma(t'+vx'/c^2)$; and *in*verse of (IIa), *viz.* (IIb), $x'=(\gamma^2/\Gamma)(x-vt)$, $t'=(\gamma^2/\Gamma)(t-vx/c^2)$. In all cases, $y'=y$, $z'=z$; $\gamma=(1-v^2/c^2)^{-1}$; Γ is independent of all coordinates, otherwise arbitrary. (In macrophysics $\Gamma=1$.) The inverse and reverse being distinct, four sets of transformation equations are required for symmetry between any two systems. For kinematics, (Ia) and its *re*verse (IIa), are fundamental. Covariance is restored by modifying the usual formalism as follows: if, for example, (Ia) is used, then contravariant tensor indices are transformed by means of the set (IaIb) but covariant indices are transformed by means of the *other* set (IIaIIb). With $\Gamma=1$. the second-order Doppler shift and the prolongation of meson life times go as γ^2 not γ. The metric tensor does not transform into itself but changes so as to maintain ds^2, $\Box$, etc. invariant. With the invariant ds a covariant formalism of point mechanics can be constructed but even without the formalism the mass velocity law $m=\gamma m_0$ follows directly as a consequence of (Ia), etc., in simple special cases.

Z3. Invisibility of the Lorentz Contraction.* JAMES TERRELL, *Los Alamos Scientific Laboratory.*—It is shown that the Lorentz contraction should not be visible, either to the eye or to a camera. Observers photographing any object simultaneously from the same position will obtain precisely the same picture, except for a change in size, irrespective of their velocity relative to the object. This effective invisibility of the Lorentz contraction follows immediately from the properties of relativistic aberration of light. If the apparent directions of objects are plotted as points on a sphere surrounding the observer, it may be shown that the Lorentz transformation corresponds to a conformal transformation on the surface of this sphere. Thus, for sufficiently small subtended solid angle, an object will appear—optically—the same shape to all observers. If methods of measuring distance, such as stereoscopic photography or vision, are used, the situation is more complicated. Precise measurements of distance to each point of the moving object, when corrected for the finite velocity of light, would of course reveal the Lorentz contraction to be present. In this sense the Lorentz contraction can be "observed," but it cannot be seen.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

Z4. Classical Electrodynamic Equations of Motion with Radiative Reaction.* GILBERT N. PLASS, *Aeronutronic Systems, Inc.*—The classical relativistic equation of motion of a charged particle has been derived in different ways by Dirac and by Wheeler and Feynman. It has sometimes been claimed that only runaway or nonphysical solutions of this equation exist because of the presence of the third derivative of the displacement. On the contrary it can be shown that there is always a physical solution of this equation for a nonsingular force. The exact solution will be given for the physical motion of a relativistic particle moving in one dimension and acted on by a time-dependent force. The acceleration of the particle is found to be a function of the Laplace transform of the force. From this result it can be shown that there is always a reasonable physical solution for the motion of the particle with radiative reaction provided that the Laplace transform of the force exists. Examples of the motion for various types of forces will be given. The motion will also be discussed when the particle is acted on by a singular force.

* This work was supported by the Office of Naval Research.

Z5. Test of the Local Isotropy of Space. HUSEYIN YILMAZ,* *Institute for Advanced Study.*—Independent of any theory there is the question of whether in a gravitational field the local velocity of light is the same in all directions. For example, is it possible to detect any difference between the vertical and horizontal velocity of light on earth by means of local measurements? From various theoretical sources it is estimated that if any relative difference exists it must be of the order of 20 cm/sec on earth. This magnitude is within the reach of modern measurements of light with the help of maser techniques. In the conventional general relativity there is a freedom of adopting isotropic or nonisotropic form of the Schwarzchild line element if the experiment favors isotropy or nonisotropy. If nonisotropy is favored the principle of observation introduced recently[1] may be ruled out.

* On leave from the Applied Research Laboratory, Sylvania Electric Products, Inc.

[1] H. Yilmaz, Phys. Rev. 111, 1417 (1958).

Z6. Coordinate Conditions for General Relativity.* JAMES L. ANDERSON, *Stevens Institute of Technology.*—Coordinate conditions can be used to reduce the number of redundant variables in general relativity, e.g., setting $g_{\mu 0}=-\delta_{\mu 0}$ eliminates these components of the metric tensor from consideration as dynamical variables in the theory. We still have a certain freedom to perform additional coordinate transformations and hence should expect that we can impose four additional coordinate conditions on the theory and thus eliminate the remaining four redundant variables. However, the freedom to perform coordinate transformations which maintain $g_{\mu 0}=-\delta_{\mu 0}$ allows coordinate conditions to be imposed only on an initial space-like hypersurface. In general, these secondary coordinate conditions will not maintain themselves off this hypersurface and hence cannot be used to eliminate additional redundant variables. While it should be possible to find secondary conditions which maintain themselves with $g_{\mu 0}=-\delta_{\mu 0}$, we have not succeeded in this effort. However, it is possible to impose other conditions on the $g_{\mu 0}$ which do lead to useful secondary conditions. In particular we can maintain the conditions $g_{12}=g_{23}=g_{31}=0$. The conditions on $g_{\mu 0}$ are determined by the combination of secondary constraints which must be added to the Hamiltonian so as to eliminate p^{12}, p^{23}, and p^{31} from it.

* This research was supported by the U. S. Air Force, Aeronautical Research Laboratory, Wright Air Development Center.

Z7. Comparison of Two Metrics for a Uniformly Accelerated Coordinate System.* JOHN BOARDMAN, *Syracuse University* (introduced by P. G. Bergmann).—The origin of a set of coordinates S' travels at a uniform acceleration $g=ac^2$ along the x axis of a set of coordinates S which is at rest with respect to S'. Whittaker[1] gives the square of the line element in S' as $ds'^2=(1+2ax)c^2dt^2-(1+2ax)^{-1}dx^2-dy^2-dz^2$, while Haantjes[2] gives this quantity as $ds'^2=\sigma^{-2}\eta^{\mu\nu}dx^\mu dx^\nu$, where $\sigma=1+ax-1/4a^2s^2$. A null-geodesic (light path) is a straight line in S; according to Whittaker's metric it is a parabola in S', while according to Haantjes' metric it remains a straight line in S'. In either case, the space S' is Euclidean. Whittaker's metric is derived from Schwarzchild's metric, while Haantjes made use of the invariance of Maxwell's laws under a conformal transformation in obtaining his metric. An error has been found in Whittaker's derivation.

* Work supported by the National Research Council.

[1] Whittaker, Proc. Roy. Soc. (London) **A116**, 720 (1927).
[2] Haantjes, Proc. Koninki Akad. Wetenschap. Amsterdam **40**, 700 (1937) *ibid.* **43**, 1288 (1940).

Z8. Commutation Relations between Observables in General Relativity.* ARTHUR KOMAR AND PETER G. BERGMANN, *Syracuse University.*—One of us has previously described a method for constructing a complete set of observables in general relativity.[1] Commutators (Poisson brackets) between any two observables may be interpreted as the (infinitesimal) change in one observable induced by the infinitesimal invariant canonical transformation generated by

the other. As this interpretation will serve as an unambiguous definition in either a Hamiltonian or a Lagrangian formalism,[2] we have chosen a Lagrangian approach. As the generating observable we use an integral over a three-dimensional hypersurface whose integrand is a linear combination of the components of the curvature tensor; the coefficients are functions arbitrary throughout the domain of integration. This calculation yields commutators between components of the curvature tensor and components of the metric tensor and its derivatives in an "intrinsic" coordinate system. We believe that the method can be extended to different generators as well, so that it will lead to commutators between any pairs of observables.

* Supported by the U. S. Air Force Office of Scientific Research and the National Science Foundation.
[1] A. Komar, Phys. Rev. 111, 1182 (1958).
[2] Bergmann, Goldberg, Janis, and Newman, Phys. Rev. 103, 807 (1956)

Z9. Riemannian Geometry and the Equations of Motion. T. F. MORRIS, *McGill University*.—The simple proof,[1] that the field equations of general relativity determine the equations of motion for particles to be geodesics, fails because the metric field becomes singular on the world lines of the particles. By using the invariant $R+a^2(R^2-2R_{\mu\nu}R^{\mu\nu})/2$ as the basis of a variational principle, a set of field equations can be obtained which in the weak field approximation become $a^2\eta^{\sigma\rho}\eta^{\mu\nu}\gamma_{\alpha\beta,\mu\nu\rho}+\eta^{\mu\nu}\gamma_{\alpha\beta,\mu\nu}=-16\pi T_{\alpha\beta}$. Solutions can be obtained which are finite on the world lines. A "radiation reaction" term, due to the self-field of a particle, is obtained in the equations of motion.

[1] Eddington, *Mathematical Theory of Relativity*, p. 126.

Z10. On Continuous Creation. WINSTON H. BOSTICK, *Stevens Institute of Technology*.—Einstein's[1] original cosmological solution which assumed that all the mass of the universe is electromagnetic in origin states that an average inward pressure $p=-\rho/2$ binds this energy into the elementary particles, and that the radius of the universe is $a=2MG/\pi c^2$, where ρ is the average density of matter in the universe and M is the mass of the universe. (Einstein's cosmological constant was not introduced in this solution.) Hoyle's[2] solution for continuous creation can be understood in a simple way in terms of Einstein's solution, for if ρ is constant and a increases (as it must in the red shift) M must increase, and hence continuous creation must proceed. It has been shown[3] that in a torus model of the elementary particle the self-gravitational potential energy E_g can be comparable in magnitude to the self-electromagnetic field energy E_f, where $E_f+E_g=mc^2$. If n is the average neutron and proton number density in the universe, Einstein's solution gives $p=-nmc^2/2$. We now identify p and E_g by putting $p=nE_g$. The average density of electromagnetic field energy E_f of particle matter (uncorrected by E_g) is $nE_f=3/2nmc^2=\rho'$, and it is $\rho'=3c^2/8\pi Ga^2$ which is in exact conformity with the density used by Hoyle.

[1] A. Einstein, *The Meaning of Relativity* (Princeton University Press, Princeton, New Jersey), fourth edition, p. 106.
[2] F. Hoyle, Monthly Notices Roy. Astron. Soc. 5, 372 (1948).
[3] W. H. Bostick, Phys. Rev. 100, 673 (1955).

Z11. Theory of Gravitation. PETER RASTALL, *University of British Columbia* (introduced by M. Bloom).—The masses of bodies and the speed of light are assumed to be functions of a scalar gravitational potential. It follows that the lengths of measuring rods and the rates of clocks depend on their positions in a gravitational field. The motion of a small particle in the field is described by a Lagrangian of the same form as that of a free particle. In the case when the field is produced by a single point mass, the usual results are found for the advance of the perihelium of a planet, for the deviation of light, and for the red shift.

SUPPLEMENTARY PROGRAMME

SP1. Solutions to the Generally Covariant Scalar Theory. HUSEYIN YILMAZ,* *Institute for Advanced Study*.†—Rigorous functional solutions to the generally covariant scalar field theory of gravitation[1] are presented. Among these there are solutions which correspond to plane and cylindrical scalar waves. It is shown that these waves carry energy and momentum. The energy-momentum tensor of these waves is a true tensor. The question of the physical realizability of some of these solutions and their relationships to Fock's coordinate conditions[2] are discussed.

* On leave from the Applied Research Laboratory, Sylvania Electric Products Inc.
† To be given at the end of Session Z if the Chairman rules that time permits.
[1] H. Yilmaz, Phys. Rev. 3, 1417 (1958).
[2] V. Fock, Revs. Modern Phys. 29, 325 (1957).

SP2. Universal Model of Semiconductor. JOSEPH G. BARREDO, *C.S.I.C.**—The chronosuperconductivity effect previously demonstrated[1] shows (1) that to establish a universal model of semiconductor the band theory derived from metals is actually inadequate, (2) that even a future theory more closely related to that of atomic bonding theory, as suggested by the Russian workers at the last International Conference on Semiconductors,[2] would be insufficient. However, it is interesting to know that the Russian workers are getting closer to the conclusions we arrive at studying the chronosuperconductivity effect. (3) That the "characteristic" semiconductor phenomena can be observed in any media, amorphous or not, provided that the inequality $t_1/t_2\gg 1$ is fulfilled, as triondynamics shows[1] (t_1 is the fusion time of the trions, as defined by the nonlinear differential equation that predicted the chronosuperconductivity effect,[1] and t_2 is the rise time of the device with which the transient semiconductor phenomena is to be observed).

* To be given at the end of Session HA if the Chairman rules that time permits.
[1] J. G. Barredo, Phys. Rev. 83, 243 (1951); J. Chem. Phys. 19, 1065 (1951); Naturwissenschaften 15, 346 (1956); Bull. Am. Phys. Soc. Ser. II, 3, 369 (1958).
[2] A. F. Joffé *et al.*, Phys. and Chem. Solids (to be published). See also Phys. Today 12, 24 (February, 1959).

SP3. Phase Shift of Power in Pulsating Stars. R. L. MOORE, *Richard L. Moore Consultants*.*—The well-known-quarter[1] cycle lag of the light in the Cepheid stars is explained on the basis of the nuclear reaction kinetics as discussed for terrestrial nuclear fission reactors.[2] The principle arises from the fact that the power density is proportional to the product of the density squared times the weighted sum of the products of the number density of the reacting particles. At the peak density more of the intermediate reacting particles are produced than instantaneously consumed. Thus their number density increases to a maximum determined by the time where the maximum negative value of $(\dot{\rho}/\rho)$ is reached. After that their number density decreases until maximum positive value of $(\dot{\rho}/\rho)$ is reached. The power density thus follows the fluctuations of number density and thereby reaches its extremes in phase with $(-\dot{\rho}/\rho)$. The role of the intermediate nuclei in the various star energy chains will be discussed.

* To be given at the end of Session B if the Chairman rules that time permits.
[1] S. Rosseland, *Pulsation Theory of Variable Stars* (Oxford University Press, Oxford, 1949).
[2] R. L. Moore, Nuclear Sci. and Eng., Suppl. 1, 2, 92 (December, 1958).

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Burwell, J. R.—F11
Butler, Daniel K.—F15
Buttrey, D. E.—Y6
Byers, N.—XA5

Cabezas, A.—K7
Cable, J. W.—H11
Cabrera, Nicholas—L1, QA8
Cahn, J. W.—QA5
Caine, C. A.—D9
Camac, M.—Y5
Cameron, A. G. W.—J14
Camp, D. C.—U10
Campion, P. J.—J11, J12
Carpenter, R. T.—SA4
Carter, R. E.—J10
Chamberlain, Owen—T11, T12, T13
Chang, C. C.—W4
Chasan, B. M.—T7
Chase, L. F., Jr.—X3
Chidley, B.—T4
Child, H. R.—H12
Childs, Charles—QA9
Chrien, R. E.—SA7, SA8
Christofilos, N.—AA4
Chupka, W. A.—FA4
Chupp, Edward L.—BA9
Clarke, R. L.—NA10, NA11
Class, C. M.—M6, U5
Cline, J. E.—SA3
Clogston, A. M.—H7, H8
Cocconi, G.—T7
Cocconi, V. T.—T7
Cochran, D. R. F.—AB12
Cochran, W.—J7
Cohen, B. L.—X11, X12
Cohen, L. D.—AB16
Cohen, Michael—J5
Cohen, V. W.—K8
Cohn, H. O.—XA3
Coleman, P. J., Jr.—BA4, BA5
Colgate, S. A.—BA7, JA8, JA11, JA12
Conner, J. P.—F13
Cornwell, R. G.—AB8
Cottingham, W. N.—XA5
Craig, P. P.—GA5
Cranberg, L.—AB3, NA12
Crane, H. R.—K1, K3
Cranston, F. P., Jr.—YA4
Crewe, A. V.—AB1
Cromer, Alan—R8
Cross, W. G.—NA11
Culwick, B. B.—T10
Cunningham, J. Richard, Jr.—H4
Curran, R.—FA1
Cutkosky, R. E.—V13

Dardis, J. G.—R2
Das, T. P.—K10
Das Gupta, K.—Q11
Davis, H. F.—T2
Davis, H. L.—H13
Davis, Raymond, Jr.—A7, BA6
Dawson, John—JA5
Dayhoff, E. S.—H3
Dekleva, J.—S8
Desjardins, S.—SA5
Desorbo, Warren—WA5
Despain, L. Gail—T3
Dessler, A. J.—BA2
Deutch, B. I.—PA3, PA4
de Vaucouleurs, G.—DA4
Devlin, G. E.—C2
Dewire, J. W.—KA8, T6
Diamond, Herbert—YA9
Dicke, R. H.—B1
Dixon, J. A.—B11
Dixon, Jack R.—CA6
Dolloff, R. T.—CA10
Donahue, T. M.—FA1
Douglass, Dean C.—B6
Dransfeld, K.—CA2
Duff, Russell E.—W5
Duffy, William Thomas, Jr.—K4
DuMond, J. W. M.—U11
Duvall, G. E.—W8, W9

Eagle, D. F.—Y8
Edeskuty, F. J.—GA8
Edwards, W. F.—U11
Efremov, N.—A2
Eklund, K. E.—U6
Enge, H. A.—X8
England, A.—KA2, KA3
Englefield, M. J.—M13
Erber, T.—Z1
Eubank, H. P.—X14
Evans, J. E.—SA2
Everhart, E.—FA3
Ewan, G. T.—YA3
Eyges, Leonard J.—V2

Fairbank, H. A.—GA6
Fairbank, W. M.—GA2
Fairhall, A. W.—AB5
Falkoff, David—HA10
Fallieros, Stavros—D4, M3
Farmer, B. J.—U5
Fast, R. W.—NA3
Faulkner, John S.—TA4
Favero, Paolo G.—Y4
Feld, Bernard T.—D14
Feldman, M.—KA8
Ferguson, J. P.—JA12
Ferrari, Fabio—R5
Ferrell, Richard A.—C9, D3, D4, M3, TA3
Fields, Paul R.—YA9
Firk, F. W. K.—SA2
Fisher, P. C.—J10
Fisher, R. A.—X8
Fite, Wade L.—Q6, Q7
Flournoy, P. A.—NA3
Fonda, Luciano—R5, XA4
Fontana, Peter—V12
Foote, James H.—T12, T13
Fowler, H. A.—FA7
Fox, J. D.—SA7
Francis, N. C.—SA11, SA12, SA13
Frank, William—R1
Franzen, W.—PA2
Fregeau, J. H.—A3
Freier, P. S.—G4, G5
Friedman, Herbert—E1
Frisch, H. L.—HA6
Fujita, S.—HA9
Fulco, Jose R.—R4
Funk, E. G., Jr.—YA1
Furth, H. P.—JA11, JA12, S10

Galey, J. A.—X2
Gallagher, C. J., Jr.—U11, YA8
Gardner, C. C.—NA7
Garfunkel, M. P.—C1
Garvin, H.—K6
Garwin, E. L.—AB1, T14, X16
Garwin, R. L.—GA7, T1
Gates, Duane C.—T9
Geiger, J. S.—YA3
Geller, S.—H5, H6
Gell-Mann, Murray—MA1
Geschwind, S.—PA15
Gettner, M.—NA2
Geusic, J. E.—PA5, PA9
Giacconi, R.—BA8, XA9
Gibson, G.—JA8
Gibson, W.—KA2, KA3
Gildart, Lee—CA9
Gilleo, M. A.—H6
Gindler, J. E.—F14
Glassgold, A. E.—R10
Glick, Arnold J.—D3
Glickstein, Stanley S.—X10
Gloersen, Per—W6
Gold, Thomas—AA2
Goldberg, Eugene—KA11
Goldberg, Leo—E2
Goldburg, Walter I.—K14
Goldsmith, P.—QA2
Goodman, C. D.—X13
Gordy, Walter—PA6, Y3, Y4
Grad, Harold—VA1
Graham, R. L.—YA3
Green, G. K.—N1
Green, T. M.—K6
Greenberg, O. W.—V6
Greene, John M.—JA3
Greider, K. R.—R10
Greuling, E.—D7
Griem, H.—FA9
Griffin, James J.—M9
Groetzinger, Gerhart—S11
Groseclose, B. C.—NA6
Gross, E. P.—B4
Grossweiner, L. I.—WA3
Grumet, A.—FA12, TA7
Gursky, H.—XA9

Hack, M. N.—V10
Haddad, Eugene—NA9
Haeberli, W.—KA6
Halbert, M. L.—KA10
Halliday, F.—JA12
Hammel, Edward F., Jr.—GA3, GA4, GA5
Hammer, C. L.—S1
Hane, M.—QA6
Harmatz, B.—YA1
Harmer, Don S.—A7, D5
Harris, E. G.—FA14
Harrison, G. R.—Q1
Hart, Philip J.—W10
Harth, E.—XA3
Harvey, J. A.—SA1
Haskin, D. M.—BA13, T16
Hassler, F. L.—X14
Hasty, T. E.—PA7
Hatch, Albert J.—FA11
Hatch, E. N.—AB9
Havens, W. W., Jr.—EA2, SA5
Hay, J. E.—X11
Heath, R. L.—U8
Hebbard, D. F.—P4
Hecht, R.—H1
Heer, E.—KA2, KA3
Heflinger, L. O.—JA13
Helfand, Eugene—HA13
Hendel, A.—XA9
Henderson, J. W.—GA1
Henkel, R. L.—F12, F13
Henry, Warren E.—H9
Herzfeld, K. F.—L4
Hess, Wilmot N.—BA9, KA7
Hill, H. A.—M11, M12, U9
Hill, J. G.—T10
Hinds, George—V1
Hirota, R.—HA9
Hobbs, Herman H.—QA8
Hoff, Richard W.—YA7
Hoffman, R.—G7, G8
Hofmann, F. W.—FA10
Hofstadter, R.—NA1
Holland, R. E.—F4
Holloway, L.—NA2
Holloway, W. W., Jr.—PA1
Holm, G. B.—F11
Holmgren, H. D.—F5, F6, F7, P3
Hommel, M. B.—BA11
Honig, A.—PA11
Hörl, E. M.—B9
Hornyak, W. F.—F5
Horwitz, Nahmin—XA8
Hough, P. V. C.—AB11
Huang, J.—T15
Hughes, D. J.—J6, SA7
Hughes, R. H.—Q2
Hughes, Vernon W.—Q8
Huizenga, J. R.—F14
Hummer, David G.—Q6, Q7
Hunting, C. E.—KA10
Hutchinson, D. D.—T1

Ikenberry, E.—HA7
Ittner, W. B., III—C3

Jackson, H. E.—T6
Jain, P. L.—BA12
Jakobson, Mark J.—FA5
Jarmie, Nelson—NA9
Jastrow, Robert—E4
Jelley, J. V.—QA2
Jenkins, Thomas L.—T9
Johnson, J. H.—M6
Johnson, John L.—JA3
Johnson, M. H.—BA7
Johnson, R. H.—W2
Johnson, William B.—T11
Johnston, Lawrence H.—KA4
Johnston, R. L.—F5, F6, F7
Jones, L. W.—S13
Jones, W. B.—KA9, Q9
Josephson, V.—JA13
Judge, D. L.—BA3

Kaplan, R.—PA13
Kaplon, M. F.—XA7
Kaminsky, M. S.—FA4
Karle, J.—L2
Karp, Ira L.—M10
Karp, S.—HA2
Katman, T. S.—X6
Katzman, J.—G3
Kaufman, A. N.—JA10
Keller, William E.—GA3, GA4, GA5
Kelley, C. H.—FA13
Kelley, Joseph G.—B8
Kelso, J. M.—BA3
Kennett, T. J.—SA9
Kenney, Robert W.—T9
Kenney, V. P.—R2
Kern, Edward L.—QA11
Kernan, W.—T14
Keuffel, J. W.—T3
Kidder, J. N.—GA2
Kikuchi, Chihiro—PA10, PA12
Kikuchi, T.—XA3
Killeen, J.—JA8, JA9
Kim, C. O.—T14
Kim, Y. W.—PA13
Kinsey, B. B.—SA2
Klebanoff, P. S.—VA4
Klein, Abraham—R12
Kley, W.—J6
Knable, N.—PA1
Knight, J. D.—AB12
Knowles, J. W.—J11, J12
Koehler, J. S.—W8, W9
Koenig, Harold R.—JA3
Kohn, Hedwig—FA10
Kohn, Walter—TA8
Koltun, D. S.—M11
Komar, Arthur—Z8

Korringa, Jan—H13, TA4
Koslov, S.—FA12, FA13
Koth, W.—WA7
Kratz, H. R.—KA9
Kraus, D.—NA2
Krieger, T. J.—SA13
Krone, R. W.—AB10
Krotkov, R.—B1
Kruse, T. H.—U6
Kuiper, G. P.—DA2

Lambe, John—PA10, WA4
Lande, K.—NA2
Langer, L. M.—U10
Larson, David—TA11
Laslett, L. Jackson—S1
Laurie, Victor W.—Y11
Lawton, E. J.—PA8
Layzer, Arthur J.—V8
Lazarus, R.—GA5
Lebowitz, J. L.—HA5, HA6
Leboy, E.—NA2
Ledley, B. G.—AB1
Lee, D. M.—GA6
Leiss, J. E.—T5
Leitner, J.—XA3
Lemonick, A.—AB8
Leonard, S. L.—JA13
Levesque, R.—F5
Levin, J. S.—AB3
Levinger, J. S.—HA4
Levinson, C. A.—M11, M12
Lewis, H. W.—AB4
Li, James C. M.—QA1
Lide, David R., Jr.—Y7
Liebowitz, Benjamin—Z2
Lillethun, E.—AB1
Limentani, S.—XA6
Lin, C. J.—CA8
Linn, D. F.—PA15
Lippman, B. A.—JA9
Lipworth, E.—K6, K7
Littauer, R. M.—KA8, T6
Livingston, M. Stanley—MA2-3, N4
Lobel, Harry—B2
Lohrmann, E.—BA12, BA13, T16
Long, M. W.—Y10
Lu, D. C.—U2
Lurio, A.—H14
Lux, R. A.—KA6
Lynch, F. J.—F4

MacDonald, D. K. C.—C11
Macklin, R. L.—EA4
Madansky, L.—P2
Magleby, E. H.—SA3
Malenka, B. J.—XA1
Malik, S. S.—F8, NA13, NA14
Malkus, W. V. R.—VA3
Malmberg, P. R.—NA5
Mandeville, C. E.—F8, NA14
Maradudin, A. A.—C12
Marcowitz, S. M.—AB1
Marcus, P.—TA5
Marrus, R.—K7
Marton, L.—FA6, FA7
Mathews, John H.—WA4
Mattox, D. M.—CA9
Maxson, D. R.—X4
Mazari, M.—X9
McCall, David W.—B6
McClure, J. W.—NA7
McDonald, Frank B.—G1, G2
McDuffiie, G. E.—H4
McGowan, F. K.—F2, F3, U12
McIlwain, Carl E.—G9
McMillan, E. M.—MA2-3
McMillan, W. G.—U1
McReynolds, A. W.—J8, J9
McVoy, Kirk W.—D2
Meechan, C. J.—QA13, WA10
Melissinos, A. C.—XA7
Melkonian, E.—J2
Meltzer, C.—XA3
Mercereau, J. E.—GA1
Meshkov, S.—M5
Metzger, F. R.—AB7, PA3, PA4
Mihelich, J. W.—YA1
Miller, C. E.—H5, H6
Miller, D. W.—F11
Miller, Donald—XA8
Miller, Jack C.—H10
Mills, F. E.—S3
Mirri, Anna M.—Y4
Mitchell, G. E.—AB4
Miyagawa, Ichiro—PA6
Moller, H. Bjerrum—J1
Moore, J. A.—J3
Moore, R. L.—JA2, SP3
Morehead, F. F.—CA12
Morgan, H. W.—Y12
Mori, H.—TA2
Morita, M.—D11
Morris, T. F.—Z9
Morrison, G. C.—X2
Moss, S. J.—KA6
Moszkowski, Steven A.—M14
Motz, H. T.—J10
Moulton, W. G.—K11, PA7
Moxon, M. C.—SA2
Murray, Joseph—XA8

Nakada, M. P.—NA7
Nankivell, J. E.—FA12, FA13
Nassiff, S.—U7
Nath, N.—NA13, NA14
Nelson, D. F.—K1
Nelson, R. R.—B11
Nerad, A. J.—W2
Nessin, M.—U6
Neugebauer, G.—T8
Neuringer, Joseph L.—JA7
Newcomb, W. A.—JA10
Newell, Homer E.—DA1
Newhouse, V. L.—C5
Newman, P. A.—A8
Newson, H. W.—X1
Newstead, Charles M.—NA15
Newton, Roger G.—XA4
Ney, E. P.—G4, G5
Nordin, P.—XA2
Novick, R.—PA1
Novick, R. A.—K8
Noyes, N. P.—R7

Obenshain, Felix E.—A6
Oberman, Carl—JA5
Ogier, W. T.—QA4
O'Keefe, J.—L3
O'Keefe, J. G.—K5
Okubo, Susumu—D8, R3
Olsen, H. N.—Q4
Omidvar, Kazem—V11
Ovenall, Derick W.—Y2
Overton, William C., Jr.—TA9

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Pake, G. E.—K13, PA14
Pal, Manoj K.—D4, M3
Palevsky, H.—J6
Panofsky, W. K. H.—N3
Pardo, William B.—AB6
Parker, Eugene—AA3
Parratt, L. G.—QA6
Parzen, George—S2
Patel, V. L.—G12
Patrick, R. M.—W7
Patten, Frank—Y3
Patterson, H. Wade—BA9
Pearlstein, L. D.—R12
Pearson, J. M.—D6
Pearson, W. B.—C11
Peaslee, D. C.—D13
Pelah, I.—J8
Penfold, A. S.—X16
Penman, S.—T1
Penner, S.—T5
Penning, J. R.—JA13
Percus, Jerome K.—V3, V4
Perel, J.—FA2
Peretti, Jean—HA8
Perez-Mendez, Victor—KA7
Perlman, Isadore—YA7
Perlman, M. L.—D5
Peterson, J. M.—NA8
Peterson, L. E.—G7, G8, G10
Peterson, T. J., Jr.—Q10
Pevsner, A.—XA3
Pidd, R. W.—K1, K2
Pinajian, J. J.—AB13
Pinkston, W. T.—AB9, M4
Plass, Gilbert N.—Z4
Pomerantz, M.—K10
Pomerantz, M. A.—G6, WA8
Pool, M. L.—YA5
Pope, N. K.—A5
Porter, Fred T.—U3
Porter, R. A.—U1
Potnis, V. R.—F8, G6
Potter, R. M.—CA7
Powell, R. S.—PA8
Prange, R. E.—C7
Price, R. E.—X11, X12
Proctor, D. G.—U8
Prosser, F. W., Jr.—AB10

Quinn, John J.—TA3

Raboy, S.—AB2, AB14
Rainwater, L. J.—SA5
Randall, J. L.—K11
Randolph, P. D.—A3
Rarita, W.—V9
Rasmussen, V. K.—AB7
Rastall, Peter—Z11
Ray, Ernest C.—G11
Ray, Wayne—S11
Rayburn, L. A.—X15
Razavy, M.—HA4
Redfield, A. G.—H1

Rees, J. R.—S7, S8
Reich, C. W.—U8
Reich, H. A.—GA7
Reilly, E. D., Jr.—SA11, SA12
Reinberg, A. R.—WA3
Reinhardt, G. C.—NA4
Reiss, Howard—HA6, W1
Reiter, R.—T4
Reynolds, D. C.—CA11
Reynolds, G. T.—BA8
Reynolds, H. L.—KA11
Ribe, F. L.—JA6
Rich, Marvin—M9
Riddiford, L.—T10
Rietjens, L. Th. —F10
Roberts, A.—T2
Roberts, J.—XA6
Roberts, J. H.—AB6
Robinson, K. W.—S6, S7
Robinson, R. L.—U12
Rockmore, R. M.—SA13
Rogers, Ernest H.—T11, T12, T13
Rogers, R. N.—PA14
Rojo, O.—HA4
Roll, P. G.—S12
Rolland, W. W.—AB4
Romanowski, T.—T4
Rose, H. J.—AB9
Rosen, Alan—BA4, BA5
Rosen, J.—SA5
Rosenberg, Leonard—HA3
Rosenfeld, A. H.—XA2
Rosenzweig, N.—SA10
Rosmarynowski, M.—FA12
Ross, A. A.—M8
Roth, H.—WA9
Roth, Laura M.—WA1
Rothman, M. A.—NA13, NA14
Rothwell, Pamela—G9
Rouvina, J.—KA9
Rubin, K.—FA2
Rush, J.—J3
Rustad, B. M.—J2, J3
Rustgi, Om P.—CA1

Sah, C. T.—B7
Sakita, Bunji—R11
Salpeter, E. E.—M15
Sartori, L.—XA10
Sawaguchi, Etsuro—H15
Scandrett, J. H.—T15
Scarl, D.—BA8
Schawlow, A. L.—C2
Schectman, R. M.—T7
Schein, Marcel—BA13, T16
Scherer, Leopoldo Colin—HA8
Scherer, P. M.—H2
Schieve, W. C.—WA8
Schlein, P.—XA6
Schlosser, H.—TA5
Schmidt, G.—FA12, FA13
Schneider, Jürgen—FA10
Schrank, G.—AB15
Schreiber, R. E.—P1
Schupp, A. A.—K1, K2
Schwartz, J.—K8
Schwarz, Helmut—B5
Schwed, Philip—S11, V9
Schwerdtfeger, C. F.—YA1
Scott, F. R.—JA14
Sello, H.—B7
Selove, W.—NA2
Seraphim, D. P.—C3
Shapiro, G.—T1
Shatas, R. A.—WA8
Sherman, R. H.—GA8
Sherr, R.—U9
Shiffman, C. A.—C6
Shore, F. J.—J1
Siebenmann, P. G.—C4
Siegel, Armand—TA12
Siegel, R.—NA2, T4
Simmons, J. E.—F12, F13
Simon, Ralph E.—QA3
Simpson, J. A.—FA6
Sims, A. R.—BA3
Singer, S. F.—BA1
Singh, J. J.—AB10
Sjoblom, Ruth K.—YA9
Skinner, Selby M.—QA11, TA10
Slaughter, G. G.—SA1
Slepian, Joseph—JA1
Slifkin, Lawrence—QA9
Small, R. L.—FA13
Smith, A. M.—S12
Smith, D. R.—U10
Smith, J. R.—J4
Smith, K.—K6
Smith, R. K.—AB3
Smith, R. V.—X3
Smith, W. G.—U12
Snowdon, S. C.—NA5
Sobottka, S.—NA1
Solmitz, F. T.—XA2
Sonett, C. P.—BA3, BA4, BA5
Sosin, A.—WA10
Soule, D. E.—CA3
Spencer, R. R.—J4
Sperduto, A.—X9
Spoerlein, R. T.—JA11
Sprenkel, Esther L.—BA6
Spruch, Larry—HA3
Spry, W. J.—H2
Staats, P. A.—Y12
Stabler, R. C.—R6
Starner, J. W.—U13, YA4
Stebbings, Ronald F.—Q6, Q7
Steigert, F. E.—S12
Steinberg, P.—XA6
Steiner, Herbert M.—T11, T12, T13
Stelson, P. H.—F2, F3
Stephens, W. E.—AB16
Stern, E.—H14
Stern, Edward A.—FA8
Stern, Frank—TA6
Sternglass, E. J.—D1
Stetson, R. F.—NA6
Stewart, A. T.—A5
Stix, Thomas H.—JA4
Stoering, J. P.—NA8
Stuart, T. P.—NA7
Stupp, E.—PA11
Sugawara, M.—R3
Sund, R. E.—YA2, YA6
Sutton, D. C.—U9
Sutton, R.—T4
Sviedrys, R.—QA6
Swann, C. P.—AB7
Swanson, F. R.—F11
Swanson, William P.—T9
Symon, K. R.—N2

Tamor, S.—S9
Templeton, I. M.—C11
Teng, Lee C.—S5
Terrell, James—Z3
Terwilliger, Kent M.—S4
Teucher, Martin W.—BA12, BA13, T16
Thomas, T. D.—YA8
Thomson, D. B.—NA12
Thorndike, A.—XA3
Thouless, David J.—C8
Tickle, R. S.—NA3
Tinlot, J.—KA2, KA3
Tomboulian, D. H.—Q10
Townsend, J. W.—E3
Trail, C. C.—AB2, AB14
Tremere, D. A.—B7
Tripp, R. D.—XA2
True, William W.—M7
Tubis, A.—R9
Tuckfiield, R.—JA14
Tunkelo, E.—J6
Tuttle, T. R., Jr.—K13

Überall, H.—D10
Uehling, Edwin A.—A9
Urey, H. C.—DA3

Van Allen, James—AA5
Vandenbosch, R.—F14
Vandenbosch, Susanne E.—YA9
Van Lint, V. A. J.—WA9
Van Patter, D. M.—F9, NA13, NA14
Vaughan, A.—Y5
Vaughn, M. T.—R3
v. Krzywoblocki, M. Z.—W3
Vogt, Erich—SA6

Wackman, P. H.—M2
Wainfan, N.—QA6
Wajima, J. T.—J2
Wales, W.—T8
Walker, E. J.—GA6
Walker, R. L.—T8
Walker, W. C.—CA1
Walker, W. D.—T15
Walker, W. W.—A4, NA6
Wallace, Roger W.—BA9, KA7
Walton, Derek—QA12
Warburton, E. K.—AB9, AB15, M4
Warschauer, D. M.—CA11
Watanabe, Shigueo—M12
Waters, J. R.—SA2
Watson, M. B.—XA2
Watson, W. W.—B8
Weatherly, T. L.—Y8, Y9, Y10
Webb, W.—B11
Webber, William R.—G1
Webster, Walter M.—W5
Weinberg, A. M.—EA1
Weinberg, Steven—V5
Weissler, G. L.—CA1
Werbrouck, A. E.—XA10
Weston, L. W.—X1
Weymann, H. D.—W11
Whipple, Fred L.—AA1
White, D. H.—T7
Whitehead, W. D.—NA3, NA4

Whittemore, W. L.—J8, J9
Whitten, R. C.—D7
Wiedenbeck, M. L.—YA2, YA6
Wiegand, Clyde—T11, T12, T13
Wiig, Edwin O.—BA6
Wild, R. L.—QA4
Wilenzick, R. M.—AB4
Wilhelm, F. J.—PA3, PA4
Wilkinson, M. K.—H11, H12
Williams, Dudley—PA5
Williams, G. H.—SA2
Williams, J. Q.—Y8, Y9, Y10
Williams, W., Jr.—AB11
Williams, Wendell S.—CA10
Williamson, R. M.—F1, X6
Wilson, R. G.—YA5
Wilson, Richard—KA1
Winckler, J. R.—G5, G7, G8, G10
Winocur, J.—K7
Winter, R. M.—C12
Winter, Rolf G.—X10
Wise, John H.—Q3
Wisseman, W. R.—F1
Witmer, Enos E.—A1
Wittels, M. C.—WA6
Wolfenstein, L.—D12
Wolicki, E. A.—F5, F6, F7
Wollan, E. O.—H11, H12
Wolsky, S. P.—CA4
Wong, C.—NA7
Wong, D. Y.—R7
Wood, D. L.—H7, H8
Woods, A. D. B.—J7
Wooten, J. K.—XA10
Wu, C. S.—U7

Yamanouchi, T.—XA7
Yen, J. T.—W4
Yevick, George J.—V3, V4
Yilmaz, Huseyin—SP1, Z5
Yntema, J. L.—X5, X7
York, C. M.—T14
Young, Donald E.—KA4
Young, H. D.—V13
Ypsilantis, Tom—T11, T12, T13

Zatzick, M. R.—X14
Zdanuk, E. J.—CA4
Zeidman, B.—X5, X7
Zemel, J. N.—WA2
Ziemba, F. P.—FA3
Ziering, S.—B4
Zipf, T. F.—T2
Zitron, N.—HA2
Zucker, A.—KA10
Zumino, Bruno—V7

Preliminary Announcement of the 1959 Summer Meeting in the East

The 1959 Summer Meeting of The American Physical Society in the East will be held in Milwaukee, Wisconsin, in the buildings of Marquette University, on Thursday, Friday, and Saturday, June 18, 19, and 20. This will be, as usual, the principal meeting of the year for our Division of Electron Physics, but other topics are by no means excluded. A Symposium on the Philosophy of Science is also planned.

Those who wish to stay on the campus of Marquette University are invited to make reservations through Professor E. D. Berners, Physics Department, Marquette University, Milwaukee 3, Wisconsin. For men there are available in Schroeder Hall double rooms which can be rented as singles for $5 per day or as doubles for $3 per person per day: these are without bath: there are also a few single rooms with bath at $6 a day. For couples there are in Boniface Hall 35 two-room apartments each with private bath at $5 per day, and such an apartment may also be taken by a couple with one child.

Those who wish to stay in hotels are asked to write to the Knights Tower Hotel (two blocks from the campus) which has a limited number of double rooms at $5.50 to $8.50 per day. A list of other hotels and of motels will be sent to anyone who asks it from Professor Berners.

Deadline for abstracts of papers to be contributed to this meeting is Friday, April 17, and the abstracts are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York.

Preliminary Announcement of the 1959 Summer Meeting in the (Very Far) West

The 1959 Summer Meeting of the American Physical Society in the West is to be held at the University of Hawaii in Honolulu on Thursday, Friday, and Saturday, August 27, 28, and 29, 1959. The Department of Physics will be our host for the meetings, and sessions will be held on the campus. There will be symposia of invited papers on low-energy nuclear physics, high-energy nuclear physics, solid-state physics, resonance physics, theoretical physics, and atmospheric and cosmic-ray physics.

There are many hotels in Waikiki, of which the Princess Kaiulani Hotel will perhaps be the closest thing to an official hotel that we shall have: its rates are $12 for a single and $14 for a double room. Following are some of the others in the Waikiki area, and their rates: Moana Hotel, $12 single, $14 double; Islander Hotel, $5 to $8 single, $7.50 to $9.50 double; Edgewater-Reef Hotel, $7.50 to $9.50 single, $10 to $14 double; Waikiki Biltmore Hotel, $8 to $11 single, $12 to $18 double; Hawaiian Village, $10 to $16 single, $12 to $18 double. Taxis between Waikiki and the University cost about $1.20, irrespective of the number of passengers; there is also bus transportation. If you wish to stay at a hotel, write to it directly, and the sooner the better. Professor K. Watanabe is chairman of the Department of Physics, University of Hawaii, and Chairman of the Local Committee, and all general requests for information should be directed to him.

The journey to Hawaii by sea is reputed to be delightful. Ships of the Matson Line sail from California every sixth day, and in particular on August 10 and 16 from Los Angeles and on August 22 from San Francisco. The journey takes four days and a half. There is a sailing of the American President Line from San Francisco on August 19 (and one from Hawaii on August 29). There are also airlines —among them, Pan American, United, Transocean, and U. S. Overseas from California, Northwest Orient from the Seattle area, Qantas Airways and Japan Airline from Vancouver. "Economy" flights are offered by Transocean and U. S. Overseas at least, perhaps by others. Bargain rates and "package tours" are said to be known to travel agents, who should be consulted.

Deadline-date for abstracts contributed to this meeting is Wednesday, July 1, and the abstracts must be sent to Professor W. A. Nierenberg, Department of Physics, University of California, Berkeley 4, California.

Sponsorship of "Topical Conferences" by The American Physical Society

For a number of years our Council has been according the sponsorship of The American Physical Society to occasional meetings organized by other groups and limited in scope to particular topics in physics. Examples are the annual Gaseous Electronics Conferences and the annual Conferences on Magnetism and Magnetic Materials. For brevity we here call these meetings "topical conferences."

The desirability of topical conferences tends to increase as the general meetings of the Society become larger. The Council at its two latest meetings has considered the situation and has set up certain stipulations for the accordance of sponsorship. Further it has authorized the creation of Committees from year to year, which in consultation with another Committee of the Council will be empowered to accord the sponsorship of the Society to topical conferences that conform with the stipulations. The Chairman of each year's Committee is to be the Vice-President of the Society for that year.

The principal stipulation—apart from the tacit one that such a conference must conduce to the advancement of and diffusion of the knowledge of physics, these being the object of the Society as stated in its Constitution—is that the conference must be open to all members of The American Physical Society. This means that all members of the Society must be allowed to attend the conference. It does *not* mean that every member of the Society has the right to give a contributed paper; the management of the conference decides who shall speak, and there is no appeal. The Council engages that the abstracts of contributed papers shall be published in our Bulletin (after the conference is over) if the management of the conference so desires and the abstracts conform to the same regulations as are imposed on the abstracts of papers contributed to our general meetings. The Council does *not* engage that the full texts of papers shall be published in any journal of the Society.

The 1959 Committee appointed to rule on topical conferences conforming to these stipulations consists of V. F. Weisskopf (*Chairman*), Harvey Brooks, W. W. Havens, Jr., and W. K. H. Panofsky.

Topical Conference on Neutron Capture Reactions

The first conference accepted for sponsorship by the 1959 Committee designated for the purpose will have "Neutron Capture Reactions" for its theme. It will be held October 1, 2, and 3, 1959, at Los Alamos, New Mexico. Any Member of the Society who desires more detailed information must write Dr. Henry T. Motz, Los Alamos Scientific Laboratory, Box 1663, Los Alamos, New Mexico.

Abstracts of contributed papers for this Conference must be received by Dr. Motz not later than August 7, 1959. Take note that it is the prerogative of the management of the Conference to accept or decline contributed papers that are offered.

Proceedings of the American Physical Society

Minutes of the 1958 Thanksgiving Meeting Held at Chicago, November 28–29, 1958

AFTER its 1957 excursion to St. Louis, the Thanksgiving Meeting returned in 1958 to its customary residence in the halls of the University of Chicago. From the beginnings of the Society this great University has been one of our three most frequent hosts. Columbia University has received us a little oftener, and perhaps the National Bureau of Standards also; but now that the former has found itself unable to contain our enormous Annual Meeting and the latter entertains only a small fraction of our Spring Meeting, the University of Chicago is going to enter first place if only we can persuade it to persevere in hospitality. Fortunately it is a sort of trinity, of which the three "persons"—the Department of Physics, the Institute for the Study of Metals, the Enrico Fermi Institute for Nuclear Studies—can pass the burden from hand to hand. In November, 1958, the burden was borne by the Department of Physics, and most especially by W. H. Zachariasen, its Chairman, and by Mary Nelson, his secretary, to whom we owe great thanks. We owe gratitude also to those who have earlier coped with our meetings and have graciously passed on their experience.

There were 160 ten-minute papers, and the registration numbered 563, each of these figures being down by about 10% from the corresponding figure of the last previous Thanksgiving. This decline we ascribe to the fact that a great meeting of the Society was held in the same place in the month of March preceding, and this we suspect took some of the papers that might otherwise have been saved up for November, even though its scope was relatively limited. We are glad that there was not a stupendous rise in attendance, for if our host were to feel overtaxed we should despair of the future of our Thanksgiving meetings. This Congress is definitely now the fourth largest of our cycle, the rank of third largest having been taken over by the March meeting. Let it remain so.

The banquet was held on Friday evening in the pleasantly familiar dining-room of the Quadrangle Club; President J. W. Beams thus had the experience of presiding over two banquets in the same place during his year of office, something that has probably never happened since the very earliest years of the Society when all the meetings were at Columbia University (but were there banquets then?). The after-dinner speakers were C. J. Overbeck and A. E. Ruark. The premeeting estimate of the attendance at the banquet proved to be exactly right, but our satisfaction is attenuated by the fact that the figure was scandalously low (130) as always at Chicago. We never understand this.

The Council met on the Friday. It named, to terms as representatives of the Society on the Governing Board of the American Institute of Physics, S. A. Goudsmit (to succeed himself) for a three-year term, and W. W. Havens, Jr., and V. F. Weisskopf for two-year terms. It elected to Fellowship the 12 candidates and to Membership the 540 whose names are appended.

Elected to Fellowship on November 28, 1958: A. B. Bestul, L. M. Branscomb, R. S. Caswell, E. G. Fuller, Martin Greenspan, Evans Hayward, R. L. Hayward, Herbert Leaderman, D. E. Mann, Irwin Oppenheim, C. H. Page, and H. O. Wyckoff.

Elected to Membership on November 28, 1958: Ryuji Abe, William H. Aberth, George R. Abrahamson, John F. Ahearne, Donald J. Albares, Jonas Alster, *Wallace T. Anderson, Jr., *Fujio Ando, Frank R. Arams, *John H. Atkinson, Jr., Lee W. Aukerman, *Luther B. Aull, III, *Roy D. Avant, Dan B. Aydelott, *Ralph Baer, James C. Baird, Barkev Y. Bakamjian, M. Balkanski, *Myron Bander, Harry R. Bowman, *Guy E. Barasch, *Robert H. Bartlett, *Raymond Bayer, *Robert R. Beasley, George D. Bender, Arlin J. Benjamin, Carlo Bernardini, Charles J. Bertuch, Paul P. Bey, John W. Bichard, *Edwin V. Bishop, James L. Blankenship, Alan Blankfield, *Haywood Blum, *Richard R. Boedeker, George H. Bolles, *Sidney L. Borison, William E. Bowers, R. T. Brackmann, Joseph V. Braddock, *Hale Van Dorn Bradt, *George W. Braun, Ernest Breitenberger, Joan Brooks, *Keith Brower, Claude T. Brown, Harmon West Brown, Jr., John Stewart Brown, *Ronald E. Brown, *W. Stanley Brown, W. Austin Bruil, *Robert A. Brungs, S.J., *Salvatore G. Buccino, *Hayati Budak, *James M. Bunch, Don L. Bunker, *Joseph C. Burgiel, *James R. Burke, Joseph E. Burke, Darnall P. Burks, *George R. Burleson, Richard P. Burns, *James C. Bushnell, Morton L. Bystock, *Laurence J. Cahill, Jr., *James B. Calvert, C. Patrick Cannon, *Robert Lee Capener, Edward J. Caris, Jr., Alan Jay Carlan, Frederick F. Carlson, Thomas A. Carlson, *D. Duane Carmony, Clinton R. Carpenter, *Paul H. Carr, Georgeanne R. Caughlan, *Robert A. Chalmers, Rhodes R. Chamberlin, *Ronald J. Chandross, *David B. Chang, Robert A. Chapman, Santimay Chatterjee, *Robert L. Chazin, John W. Childress, III, Lue-Yung Chow, John R. Christman, Alexander H. Clark, *David J. Clark, Myron A. Cohen, Richard S. Collier, William J. Condell, Jr., Robert J. Corruccini, *Roger Spencer Cortesi, *Joseph C. Coster, *Charles B. Creager, Arthur J. Critchlow, *John Cumming, William F. Cummins, Jr., Hubert Curien, *Stanley B. Curtis, Tara P. Das, *Montie G. Davis, Philip W. Davis, *Roger B. DeBar, Daniel L. Decker, Heinrich Derfler, George V. Deverall, Shaun Devlin, *Thomas J. Devlin, Jr., *William E. Dibble, *Paul W. Dickson, Jr., Edmund DiMarzio, Theron K. Dobbins, Peter N. Dobson, Jr., Doane Douthett, *Robert C. Dowling, *John E. Drumheller, *James E. Dueker, Arthur G. Duneer, Jr., Byron L. Dwelle, Jr., *Palmer Dyal, *Norman M. Edelstein, Ronald D. Edge, *Gerald Ehrenstein, Eugene Eichler, *William W. Eidson, Thomas D. English, Thomas L. Estle, *Kenneth M. Evenson, Wilfred C. Fagot, *David S. Falk, *Edward N. Farabaugh, Andrew J. Farkas, *Bobby Joe Farmer, *John W. Ferman, *Carl Fichtel, Lewis Filler, Robert C. Filz, *Charles R. Finfgeld, *Paul Finkler, Erwin Fishman, Francis E. Flaherty, Jr., *Philip A. Flournoy,

William D. Foland, Robert T. Folk, *Roger Q. Fong, *Peter R. Fontana, George Ford, Joseph Ford, William T. Foreman, Walton Forstall, Morton M. Fortgang, *David B. Fossan, Alvin Gibbs Fox, George W. Francis, Donald C. Freeman, Jr., Joan M. Freeman, Robert D. Freeman, *Joseph L. Friedes, Joseph N. Friedman, Shigaji Fujita, *Richard M. Fuller, *Herbert O. Funsten, *Fletcher Gabbard, Stanley W. Gabriel, *E. Stanley Gall, G. A. Gallup, Ross Garrett, *J. David Gavenda, *Frank L. Gebhart, Tor Ragnar Gerholm, Edwin S. Gibbs, Joseph F. Gibbs, Donald N. Gideon, E. A. Giess, *James E. Gill, *Homer H. Glascock, Jr., I. I. Glass, *Robert Glosser, *L. Peter Gold, Edwin Goldin, Harold J. Goldman, Charles M. Goldstein, *Arthur C. Gossard, *Peter V. Gray, *Thomas M. Green, III, Hans R. Griem, John S. Griffith, *B. Clark Groseclose, Robert A. Gross, Mark Gusakow, *Brother Mark Guttmann, F.S.C., James E. Hacke, Jr., David S. Hacker, *Donald E. Hagge, *Basil W. Hakki, William J. Hall, *Clifford W. Hand, *Bernis O. Hannah, Roy H. Harada, Otto K. Harling, *Samuel M. Harris, William D. Hartford, *Richard W. Hartung, *Leslie D. Heggie, Roland L. Heid, Chonon Heller, William J. Helm, Wallace D. Henderson, *Herbert M. Hess, *Jack H. Hetherington, Hiromasa Hirakawa, Lothar Hoffmann, Maurice Holt, *Robert J. Homsey, Edward W. Hones, Jr., William J. Hooker, Sister Mary Howard, S.N.D., Robert J. Howerton, *David A. Howe, Joseph Hsu, O. K. Hudson, Kenneth Hulet, Richard O. Hundley, *Douglas C. Hunt, Erich F. Huster, Tomonori Hyodo, *Jugoro Iizuka, *Leonard Indyk, *Robert L. Ingalls, Kazuo Ito, *Etsuyo Itokawa, Maurice R. Jacob, Suresh C. Jain, *Robert C. Jaklevic, Joseph N. Jansen, *Steven M. Jarrett, *Sister Mary Jendrzejewski, C.S.B., Tung Hon Jeong, Anthony J. John, Donald S. Johnson, Frank F. Johnson, *William B. Johnson, *William P. Johnson, *Eric D. Jones, Clyde P. Jupiter, *Joseph Kahane, Hung Kuen Alan Kan, Junjiro Kanamori, *Edwin Kashy, *Charles Kaufman, *Robert J. Kearney, Seymour P. Keller, *Ralph Edward Kelley, James M. Kendall, Jr., *Edward F. Kennedy, Jr., Paul Kenneth, *Klaus G. Kerris, Kun Hee Kim, *Y. W. Kim, *Young Suh Kim, John H. Kineke, Jr., Alan J. Kiser, Alan Lee Kistler, J. Wilhelm Kluver, *Robert H. Kohler, Earl L. Koller, *Raymond M. Kosiewicz, *Morton D. Kostin, Arthur R. Kotz, *Peter Kotzer, *Stanley B. Kowalski, John F. Krasny, *Marshall Kreitman, *Jefferson B. Krumme, *Robert F. Kubin, *Arthur F. Kuckes, *John L. Kulander, *Krishna Kumar, Walter Kundig, *Herbert L. Kyle, Albert H. LaBov, *Joseph Lach, Janine R. Lardinois, *Amulyalal Laskar, *L. W. Lau, *James C. Legg, *Manfred Leiser, *Darryl Jay Leiter, *Melvin Leon, *Ira W. Levin, James E. Lewis, Myron R. Lewis, Alan B. Lidiard, *Harold B. Liemohn, *Barry J. Liles, *Samuel Lindsay, II, George F. Linnstaedt, *Lester Lipsky, *Daniel B. Lister, W. A. Little, *Caroline S. Littlejohn, David C. Liu, Frederick F. Liu, *David I. Lobel, John M. Lohse, *Frank J. Low, Peter G. Lykos, Shigeru Machida, Kenneth M. MacIntosh, Cleon A. Mackliet, William V. Macnabb, *Visweswara L. Madhyastha, *Fouad G. Major, Richard E. Malenfant, *Fred K. Manasse, Paul C. Mangelsdorf, Jr., Matteo Mangiacotti, Michel B. Martin, *Taku Matsuo, Brenton L. Mattes, James H. McCrary, Richard J. McQuillin, Thrygve R. Meeker, David Mehl, Herbert A. Melhorn, M. A. Melehy, *Victor J. Melfa, Adrian C. Melissinos, *Carl M. Meltzer, Josh Menkes, *Alfred W. K. Metzner, Owen L. Meyer, Verena Meyer, Paul A. Michael, Ritchie P. Mikesell, Douglas G. Miller, W. Robert Miller, Jr., Laurence W. Mills, Jr., *Wayne A. Mills, *Ramzi H. Misho, Morton Mitchner, Paul F. Mohrbach, Maissinsky Moise, James F. Mollenauer, *Monte N. Monson, *Donald R. Morgan, Toru Moriya, Eric Morris, Paul M. Moser, G. Dietrich Muller-Hillebrand, Emil M. Murad, John G. Myers, Ali M. Naqvi, *Eugene Newman, Jr., *N. Robert Nilsson, John Denys Nixon, *Emory Nordberg, Enrique L. Oelker, Willard O. Olson, Mituo Ono, *Stephen Orenstein, Charles J. Orth, Hendrik J. Oska, J. Fletcher Osterle, Manoj Kumar Pal, Emanuel Papadopulos, Richard A. Pappert, Hans H. Paproth, Henry J. Passerini, *Jack M. W. Patrick, *James D. Patterson, Derek A. L. Paul, *Hans-Otto Paulussen, *Arthur D. Payton, Jr., *John Davie Pearson, *Michael Pearson, T. P. Pepper, *Thomas J. Peterson, Jr., Maurice Peyron, *Howard T. Phelan, *William Roy Pierson, Gerald P. Pighini, Cornelius J. Pings, *Ralph L. Place, Marvin Polan, Lawrence M. Politzer, *Michael Pollak, *Joseph W. Pollard, *Richard E. Pontinen, *Robert P. Poplawsky, John K. Powers, *Robert S. Powers, *Donavon D. Pretzer, Robert Eugene Price, Simon M. Pristoop, *Kedan D. Pyatt, Jr., Tracy K. Pugmire, Nathaniel H. Pulling, Benjamin Rabinovici, Paul J. Rabinowitz, John L. Ragle, *William C. Ramsay, Daniel M. Raskin, Dominic J. Raso, *Reuben N. Rechtschaffen, Charles W. Rector, Robert F. Redmond, Earl J. Reinbolt, Charles J. Repper, Donald R. Rhodes, *Edward J. Rice, Robert Bruce Rice, *William D. Rice, Walter F. Rich, Allan C. B. Richardson, Harold M. Richardson, John DeWitt Riggin, John P. Rink, Mark T. Robinson, Hermann R. Robl, Hans M. Roder, *William W. Rolland, *William K. Rose, *Billy E. Rosenbaum, *Joseph S. Rosenshein, Joseph R. Roth, Morton Rudin, Rudolph Rust, *William M. Sackinger, Harold Saltzman, Selden Saunders, Earl S. Schlegel, Ronald D. Schmickley, George Schmidt, Richard E. Schmunk, *Albin E. Schraeder, J. B. Schroeder, Clyde H. Schweinsberg, *Alvan Segal, *John J. Sein, Hyman Serbin, Gerald W. Sharp, Harlan C. Shaw, *Michael F. Shea, Boris Sheleg, Rindge Shima, *Maung Hla Shwe, *Paul Siegel, *Isaac F. Silvera, *William G. Simon, John B. Singletary, *William L. Skeel, Charles H. Skeen, *M. H. Skolnick, *Malcolm J. Skove, *Norman Slagowitz, *Richard W. Slocum, Jr., *Gerald A. Smith, G. Pedro Smith, James P. Smith, *Lewis P. Smith, Richard J. H. Sneed, Allen L. Snyder, *Lawrence C. Snyder, *Toshio Soda, Junkichi Sohma, Nicholas Solntseff, *Donald E. Spiel, *Carole M. Stearns, *William H. Steier, *James J. Stekert, Emanuel Stern, *Robert F. Stetson, *Robert J. Strain, Karl J. Strnat, Richard E. Stroup, Henry G. Stuebing, Austin J. Sullivan, Edward J. Supernowicz, *Rollin J. Swanson, Minoru Takeda, Mostafa E. Talaat, Murray A. Tamers, Frank I. Tanczos, Niyazi Tarimer, *George O. Taylor, Jr., Melvin T. Thieme, *Wilkin E. Thomas, Jr., *Edward H. Thorndike, Walter R. Thorson, *Robert S. Tickle, *Martin S. Tiersten, Henry F. Timmons, *Timothy E. Toohig, S.J., *Paul A. Treado, *C. H. Tsao, Thomas R. Tuttle, Jr., Vincent H. Uhlenkott, *Donald R. Uhlmann, Earl M. Uram, Thomas A. Vanderslice, Jan Van Kranendonk, Gurdeva S. Verma, Guido L. Vidale, Dietrich H. Vincent, *James S. Vincent, Walter G. Vincenti, Leopold von Grun, A. M. Morgan Voyce, *Bernard J. Waclawski, *William W. Walker, *Richard L. Walter, *George K. H. Wang, *Wirt C. Ward, *Shelia J. Warren, Julian Wasserman, *Allan Wasson, *Richard E. Watson, William H. Watson, Jr., Howard J. Wayt, *Alfred Weinberg, *E. R. Weiner, Bruno O. Weinschel, *Robert E. Welsh, John C. Wheatley, Samuel F. Whiteside, Daniel Willard, *Kenneth G. Wilson, William M. Wilson, Ulrich E. Winkler, Emergy C. Wisman, Clarence J. Wolf, *Neil S. Wolf, Hendricus M. Wouters, Hide Yoshioka, Carlton S. Young, Edwin A. Zaratkiewicz, *Richard A. Zdanis, *William B. Zeleny, and Klars Ziock.

Errata Pertaining to Abstracts A5, E10, G14, J10, J12, M5, M6, and SP1 of the 1958 Chicago Bulletin

(Series 2, Vol. 3, No. 7)

A5, by S. Ofer. In lines 12 and 13, instead of "The 200-, [illegible]=13.8311" read "$b^*=8.608$." Also in line 15 instead of "$v^*=c/1.002627$" read "$v^*=c/1.01367$."

E10, by Nahmin Horwitz, Donald Miller, Joseph J. Murray, Melvin Schwartz, and Horace D. Taft. The title should read: "K^- Absorption in Deuterium: Evidence for the Two-Step Process $K^-+d\rightarrow(\Sigma+\text{Nucleon})+\pi^-\rightarrow(\Lambda+\text{Nucleon})+\pi^-$." In lines 5 and 6, instead of "Approximately Σ^- mesons have been stopped in the . . ." read "Approximately 2200 K^- mesons have been stopped in the ···."

G14, by J. H. Gibbons and R. L. Macklin. The title should read: "Total Cross Section for $T(p,n)He^3$."

J10, by Gertrude Tiring Schwarzmann. In line 3, instead of "momentum 1920 Mev/c" read "momentum 1190 Mev/c." In line 14, instead of "momentum $273m_l\times13.795$ c," read "momentum $273m_e\times8.55$ c." In line 15, instead of "b^*

J12, by E. J. Schremp. In line 7, instead of "$\psi_\pm\rightarrow\psi_{\pm^0}=\mp\bar{\psi}^\pm$" read "$\psi_\pm\rightarrow\psi_{\pm^0}=\mp\bar{\psi}_\mp$." In line 10 instead of "$\psi^0=\|n^c-p^q\|$" read "$\psi^0=\|n^c-p^c\|$." In line 18, instead of "$\psi=\|pnn^c-p^c\|$" read "$\Psi=\|pnn^c-p^c\|$."

M5, by A. C. Melissinos and S. P. Davis. In line 6, instead of "in the 15th order" read "at 63°." In line 12, instead of "$\mu_{197^*}=-1.037\pm0.020$" read "$\mu_{197^*}=-1.04\pm0.01$." In the displayed equation, instead of "$Q_{197^*}=(+1.50^{+0.80}-0.75)\times10^{-24}$ cm^2" read "$Q_{197^*}=(+1.5\pm0.3)\times10^{-24}$ cm^2."

M6, by W. Faust, M. McDermott, and W. Lichten. The title should read "hfs of the Metastable $^3P_2$ States of Hg^{199}, Hg^{201}, Cd^{111}, and Cd^{113} by the Atomic Beam Method."

SP1, by E. J. Schremp. In line 7 instead of "$e^{\pm2i\omega_0 s^2}=-e_0$" read "$e^{\pm2i\omega_0 s^2}=-e_0$." In line 22, instead of "$\psi_\pm=(\mu_{\pm^0}+v_{\pm^0})/\sqrt{2}$," read "$\psi_\pm=(u_{\pm^0}+v_{+^0})/\sqrt{2}$." In line 23, instead of "$\psi_\pm=(u_{\pm^0}+v_{\pm^0})/\sqrt{2}$" read "$\psi_\pm=(u_{\pm^0}+v_{\pm^0})/\sqrt{2}$."

Minutes of the Conference on Sector-Focused Cyclotrons at Sea Island, Georgia, February 2, 3, and 4, 1959

THE American Physical Society and the National Research Council jointly sponsored a conference on sector-focused medium energy cyclotrons which was held at Sea Island, Georgia, on February 2, 3, and 4, 1959. Sessions were held in the mornings from 9:00 until 12:45, and in the afternoons from 2:00 to 5:30, with a half-hour coffee break during each session.

No detailed programme had been set up in advance of the meeting, since completely informal discussion was desired. The general topics for discussion and the session chairmen were selected by the programme committee (W. W. Havens, Jr., H. W. Koch, and A. H. Snell). Each conferee who wished to make a contribution was invited to make arrangements with the session chairman.

The topics for discussion and the session chairmen were as follows:

Monday:

Orbit Calculations and Magnetic Field Design:
D. L. Judd, *Lawrence Radiation Laboratory.*

Realization of Required Field Configurations and Magnet Model Work:
E. L. Kelly, *Lawrence Radiation Laboratory.*

Tuesday:

Radiofrequency Systems:
J. R. Richardson, *University of California at Los Angeles.*

Beam Quality:
R. S. Livingston, *Oak Ridge National Laboratory.*

Beam Extraction:
T. A. Welton, *Oak Ridge National Laboratory.*

Wednesday:

Description of Existing Sector-Focusing Cyclotrons and Shielding:
H. W. Fulbright, *University of Rochester.*

External Focusing Systems, Instrumentation, Operational Experience and Summary of Outstanding Problems:
W. W. Havens, Jr., *Columbia University.*

The possible methods of publishing the information to be presented at the meeting were outlined at the beginning of the conference by A. H. Snell. Several discussions on this subject were held during the meeting, and it was agreed that it would be more desirable to print an edited "proceedings" of the conference as a book rather than to publish the abstracts of contributed papers in the Bulletin of the American Physical Society and the survey papers in *The Review of Scientific Instruments.* These proceedings will be available from the National Research Council, 2101 Constitution Avenue, Washington 25, D. C., as National Research Council Publication No. 656, Nuclear Science Series Bulletin No. 26.

The meeting was attended by 86 physicists from 39 institutions in six countries. Most of the people who attended the meeting felt that this conference was very profitable. As the conferees lived closely with their counterparts from other laboratories for several days, they became well acquainted, and there was adequate time and opportunity for detailed discussions of even the most elusive points.

Unfortunately, the weather did not favor the conference, being foggy and rainy during most of three days on which the conference was held. This brought about a much better attendance at the meetings than would have been the case had the weather been clear and balmy. During the few hours of sunshine on Tuesday, most of the conferees had lunch at the Beach Club, an elegant building surrounded by palm trees and spacious gardens overlooking the Atlantic. The attendance at the Tuesday afternoon session dropped by a factor of two. The tennis courts, the lush foilage surrounding the pastel-colored buildings, and the five miles of broad sandy beach pounded by the ocean waves provided a stronger attraction than the sessions on cyclotrons.

Despite the inclement weather, the elegant atmosphere of the Cloisters (the hotel at which the conference was held) and the superb cuisine made the hours which were not spent in discussion of cyclotrons also very pleasant.

W. W. Havens, Jr.

CANDIDATE: DO NOT SEND ANY MONEY TO US OR ORDER JOURNALS UNTIL YOU RECEIVE NOTIFICATION OF ELECTION TO MEMBERSHIP.

The American Physical Society

NOMINATION FOR MEMBERSHIP OR FELLOWSHIP

(cross out inappropriate word)

To be sent to KARL K. DARROW, Secretary, Columbia University, New York 27, N.Y.

We hereby nominate for MEMBER / FELLOW in the American Physical Society

Name of person nominated.....
(First name) (Middle name) (Last name)

Name in full, the parts of the name ordinarily omitted being in parenthesis—e.g., John S(tuart) Smith

P. O. Address.....
which the candidate would wish to use as a member

.....

.....

Information as to positions, degrees, and qualifications for Membership or Fellowship. A nomination for Fellowship must be accompanied by a full statement of services and contributions to physics. (See other side).

.....

.....

.....

.....

Signatures of two Members or Fellows making the nomination.

.....
Signature

.....
Please PRINT Name under Signature

.....
Signature

.....
Please PRINT Name under Signature

Dated.....19.....

The signatures of two sponsors, who must be Fellows or Members of the Society, are required. This applies to nominations to Membership, and it also applies to nominations to Fellowship regardless of whether or not the nominee is already a Member. In the case of a nomination to Fellowship a list of the nominee's researches, publications, and other contributions to physics is required, and must be given overleaf or on an attached sheet. For details of the election-procedure, see the Constitution of the Society.

IF THE CANDIDATE IS A STUDENT — A new member who is "a **full-time** student regularly enrolled in an educational institution" may have special privileges for one year, if, when nominating him, one of his nominators certifies that he is such a student — SEE OTHER SIDE.

DETAILED STATEMENT
of the
CANDIDATE'S QUALIFICATIONS

In the case of a nomination to Fellowship, whether or not the nominee is already a Member, a list of the candidate's researches, publications, and contributions to physics is required and should be given on this page or on an attached sheet.

IF THE CANDIDATE IS A STUDENT, ONE OF HIS SPONSORS MUST SIGN THE FOLLOWING STATEMENT IN ORDER TO OBTAIN FOR HIM THE SPECIAL PRIVILEGES GRANTED TO STUDENTS.

I hereby certify that .....
is a regularly-enrolled full-time student in an institution of learning.

.....
(Sponsor)

Take note that the candidate loses all claim to the special privileges granted to students if the foregoing certification is not signed when the nomination-form is sent to the office of the Society.

MEETINGS AND DEADLINES FOR THE REMAINDER OF 1959

Place	*Meeting dates*	*Deadline date*
Cambridge, Massachusetts	March 30, 31, April 1	past
Washington, D. C.	April 30, May 1–2	past
Milwaukee, Wisconsin	June 18–20	April 17
Honolulu*	August 27–29	July 1
Chicago	November 27–28	September 25
Pasadena*	December 28–30	October 23

* Abstracts for the Honolulu and Pasadena meetings are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline day often fail to arrive in time: the last postal delivery of the day usually comes to our office before 2 P.M. Allow at least two days for abstracts sent by airmail from points east of the Mississippi, and longer for those sent from farther west. Abstracts postmarked (at the point of dispatch) on deadline day are instantly rejected, and telegrams heralding their arrival are fruitless except in revenue to the telegraph company. Special delivery is usually useless and sometimes worse than useless. *The privilege of contributing papers to meetings of the American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

TOPICAL CONFERENCE (see page 302)

Los Alamos	October 1–3	August 7

Abstracts for this conference are NOT to be sent to the office of the Society nor to the Local Secretary for the Pacific Coast. See page 302.

RULES AND INSTRUCTIONS FOR THE PREPARATION OF ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten; *one must be an original*, the other may be an original or a carbon copy. *Carbon copies will not be accepted in lieu of originals:* they smear. *Abstracts must be double-spaced:* single-spaced manuscripts are too crowded to permit the editorial markings to be made with ease and clearness. *Each abstract must be confined to a single page:* if it is too long for a single page it is too long to be printed. If we receive an abstract typed on two pages, we print only its first page. *Write each abstract as a single paragraph:* the suppression of paragraphs costs time and labor to the editors. *Do not use very thin paper:* a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. *Telegraphed abstracts are refused.* The American Institute of Physics will bless you if you type first the title of your abstract in lower-case with capitalized initials, then your name in capitals, then the name of your institution in lower-case underlined. Issues of the *Bulletin* are always appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

It has now become an expensive business to make any change in an abstract, even the smallest, after the abstract has gone to press. By order of our Council "A change in an abstract will be permitted only at the discretion of the Secretary or his deputy, and only if TEN DOLLARS is enclosed with the letter in which the change is requested." As heretofore, an abstract will not be withdrawn from proof unless the asker sends ten dollars with his request.

The American Physical Society

OFFICERS OF THE SOCIETY FOR 1959

President	G. E. UHLENBECK	University of Michigan
Vice-President	V. F. WEISSKOPF	Massachusetts Institute of Technology
Secretary	K. K. DARROW	Bell Telephone Laboratories (*retired*) (Office at Columbia University)
Treasurer	S. L. QUIMBY	Columbia University
Managing Editor	S. A. GOUDSMIT	Brookhaven National Laboratory

Past Presidents now on Council: W. F. G. Swann, E. P. Wigner, H. D. Smyth, and J. W. Beams.

Elected Members now on Council: S. K. Allison, N. F. Ramsey, Walker Bleakney, W. K. H. Panofsky, W. A. Fowler, Charles Kittel, Harvey Brooks, and Charles Hard Townes.

Local Secretary for the Pacific Coast	W. A. NIERENBERG	University of California, Berkeley
Deputy Secretary	W. W. Havens, Jr.	Columbia University